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A LANDSAT Study of Ephemeral and Perennial Rangeland Vegetation and Soils

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The project as originally outlined in the Memo of Understanding between BLM and NASA, has been expanded considerably. BLM has expended an additional $40,000 dollars for the analysis of LANDSAT satellite data in the form of computer-compatible tapes (CCT's) in an attempt to develop procedures for obtaining information useful for mapping vegetation and soil parameters.

16. Abstract
Several methods of computer processing were applied to LANDSAT data for the purpose of mapping vegetation characteristics of perennial rangeland in Montana and ephemeral rangeland in Arizona. The choice of optimal processing technique is dependent on the prescribed mapping task and site condition. Single channel level slicing and ratioing of channels were used for simple enhancement. Predictive models for mapping percent vegetation cover based on data from field spectra and LANDSAT data were generated by multiple linear regression of the six unique LANDSAT spectral ratios. Ratio gating logic and maximum likelihood classification were applied successfully to recognize plant communities in Montana. Maximum likelihood classification did little to improve recognition of terrain features when compared to a single channel density slice in sparsely vegetated Arizona. Our studies indicate that LANDSAT is more sensitive to differences between plant communities based on percentages of vigorous vegetation than to actual physical or spectral differences among plant species. Recommendations for development of an operational system for the Bureau of Land Management are included.

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PREFACE

This report outlines research accomplished as a continuation of work completed during the first year of the ERTS satellite program. A report was made to NASA March 31, 1974, entitled "Predict Ephemeral and Perennial Range Quantity and Quality During Normal Grazing Season".

The objective of research reported here is to continue the investigation into the possibility of using satellite imagery to classify important soil and vegetation parameters. Test sites were selected in the arid ephemeral and ephemeral-perennial rangelands of Arizona and the perennial rangelands of southeastern Montana in order to investigate a wide variety of climatic conditions found on lands managed by the Bureau of Land Management (BLM). Standard BLM procedures were used for collecting field data in an effort to test a system which would be most useful to Bureau resource managers on an operational basis. An additional objective of the study was to provide training of BLM personnel in the use and understanding of machine-processed LANDSAT data.

Broad-band spectral reflectances corresponding to the four LANDSAT MSS channels were measured on typical plants and soils found on the study sites. Reflectance data of most plants and soils that are important to managers of natural environments are not available in the literature. It was felt that such data would improve understanding and assist in developing a model or models for classifying plant communities. Development of models and other processing of LANDSAT data were performed by the GeoSpectra

Corporation, Ann Arbor, Michigan. The BLM personnel provided field knowledge as required in the investigation. Additional processing of LANDSAT data was done on the MDAS system at Bendix Aerospace, Ann Arbor, Michigan.

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A LANDSAT STUDY OF EPHEMERAL AND PERENNIAL RANGELAND VEGETATION AND SOILS

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SUMMARY

The Federal Land Policy and Management Act of October, 1976, has charged the Secretary of the Department of the Interior with the task of keeping current the inventory of resources on public lands. Proper management of the natural resources and activities on these lands requires up-to-date terrain information for 68.8 million hectares in the western U.S.. Research has been conducted on two test areas, perennial rangeland in Montana and ephemeral rangeland in Arizona, on methods of computer-processing LANDSAT satellite multispectral data to provide plant density and composition information to aid in the continuing inventory process. The wide area, multitemporal coverage provided by LANDSAT, with multispectral coverage which is both sensitive to vegetation differences and relatively free of geometric distortion, gives promise for its use as a tool in rangeland management.

Computer-processed LANDSAT data investigated during this study showed that choice of processing technique is dependent on the mapping task prescribed and site conditions. Density slicing of a single channel of data, MSS channel 5, resulted in the recognition of plant communities to the extent that their delineation is influenced by topography, exposure, depth of soil, and the albedo of underlying soils in the perennial rangeland. The sparse vegetation in the ephemeral rangeland resulted in little vegetative information in MSS channel 5, and features recognized seemed to relate most to differences in soil types. This result, however, does allow improvement in vegetation mapping due to the strong influence of geology and soil conditions on vegetation.

Ratios of LANDSAT channels helped to reduce environmental factors contributing to spectral differences, such as topography and sun angle, recognizing more sensitively levels of percent vegetation independent of terrain features. Both products are useful; while topography is an important consideration in livestock grazing patterns, a knowledge of vegetation cover is needed for determining living grazing capacity and trend in range condition.

Two different decision rules were applied to data in Montana for automatic recognition of plant communities defined by field observations. Ratio gating logic applied to five ratios resulted in 72% classification of the scene. Accuracy was target dependent and was not adequate for application in an operational system. Maximum likelihood classification applied to four MSS channels resulted in greater than 99% recognition and the accuracy achieved shows possible operational uses. Maximum likelihood classification lent little improvement over a single channel level slice in mapping of ephemeral rangeland in Arizona. Other automatic recognition procedures which were not applied may be found to be more useful in plant community recognition. However, our studies indicate that whatever the decision rules applied to mapping of plant composition with LANDSAT data, the spectral configuration seems to be more sensitive to differences based on percentages of vigorous vegetation than to actual physical or spectral differences among plant species.

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1.0 INTRODUCTION

1.1 LANDSAT in Rangeland Management

> "The Secretary shall prepare and maintain on a continuing basis an inventory of all public lands and their resource and other values..., giving priority to areas of critical environmental concern. This inventory shall be kept current so as to reflect changes in conditions and to identify new and emerging resource and other values."
>
> PUBLIC LAW 94-549
> Section 201(a)
> October 21, 1976

The United States Department of the Interior (USDI), Bureau of Land Management (BLM), administers the natural resources on approximately 68.8 million hectares (170 million acres) of national resource lands (NRL), in the ten western states, exclusing Alaska. These lands are extremely varied in climate, topography, geology, soils and vegetation. Some lands are well blocked into large concentrations of public lands, while others are scattered among private and state lands.

Most of the national resource lands are grazed by livestock at some time during the year. Proper management of grazing animals allows native forage to be harvested without damage to other resource values such as wildlife habitat or watersheds. This requires movement of livestock at critical times during a grazing season in order to provide needed rest to plants and soils. Certain information about the range condition is needed for sound management. This information includes: species composition within a plant community, the percent of ground covered by live vegetation, phenological stages of development for key species of plants, forage production, the condition of the range (plant vigor), and trend in range condition.

Resource data on soils and vegetation necessary for proper management of so much land is difficult and costly to obtain and keep updated. Prior to 1965 the BLM attempted to update range condition information on one fifth of its rangelands each year. Since that time no such studies have been made, except on isolated ranges under intensive management. Public Law 94-549 requires that in the future the BLM make resource inventories on a continuing basis. Accurate and efficient methods of making inventories of vegetation and soil and monitoring forage production and range condition are needed.

During the first two years after the launch of ERTS-1, BLM studies of the usefulness of satellite imagery involved the visual analysis of color composite and black and white images. Bentley (1974, 1976) found that satellite imagery could be used to map broad soil types, plant communities and forage production on a regional basis. Carneggie, et al. (1974) found that sequential satellite imagery was useful for monitoring phenology, forage production, and forage condition of annual forage plants in the Mediteranean annual grasslands of California. Maxwell and Johnson (1974) found that vegetation types, range condition and green biomass classes could be mapped by satellite imagery on a typical short grass prairie on the Pawnee National Grassland in northeastern Colorado. Krumpe (1973) found vegetation can be mapped from ERTS color composites. Expanding upon this work, Nichols, et al. (1974) found that machine processed satellite imagery was useful in the inventory of timber volume on a regional basis.

Use of ERTS and LANDSAT imagery for gathering resource information has had several drawbacks. The level of detail which can be obtained is limited by the quality of the photographic product and what the human eye can discern. The resulting information is on a regional scale. In many cases the satellite data was only one of several levels of imagery used to obtain the desired information, or it was used to extrapolate information derived from larger scale imagery over a broader area. In an operational program, conventional or high level aircraft photography is not always available and is expensive to obtain.

The first attempt by the BLM to utilize computer enhanced satellite data was carried out by inventigators at the Forestry Remote Sensing Program, University of California at Berkely, under contract to the BLM. Nearly 404,686 hectares (1 million acres) of NRL in the Susanville, California BLM district were classified into major vegetation communities by Colwell, et al. (1975). Their research, however, utilized multistage sampling with three levels of satellite and aircraft imagery.

The research outlined in this present report was an attempt to map vegetation and soil parameters from computer processed LANDSAT data without the aid of larger scale aerial photography. Also, fundamental research was undertaken in the use of field spectra for creating multispectral models of processed LANDSAT data.

1.2 Objectives

The technological objectives of this study were:

1. Construct theoretical models of plant community spectra in Montana and Arizona from visible-reflective infrared spectra and ground cover estimates measured by the BLM scientists in the field.
2. Determine if selected plant communities can be discriminated with LANDSAT data using automatic recognition maps produced from ratio gating logic.
3. Search for special functions (linear combinations of single channels and ratios) which would map percent vegetative cover in both states, percent grass cover in Montana, or other physical parameters.
4. Determine from theoretical plant community spectra of four times of year in Montana and two times of year in Arizona which spectral parameters are best for discriminating physical parameters (percent vegetation, percent grass, etc.) by multitemporal processing, such as temporal ratioing.
5. Compare recognition of plant communities in Montana and Arizona accomplished by maximum likelihood decision on single channels to that done by gating logic with ratios;

also to recommend how each logical theory should be used for operational remote sensing at the BLM.

6. Make recommendations for future research and operational systems for rangeland monitoring by the BLM.

1.3 Arizona Test Area

Arizona was selected for study because it is representative of a large portion of the arid and semi-arid rangelands managed by the BLM in southern California, central and southern Arizona and southwestern New Mexico. Nearly all of these arid rangelands are grazed by livestock during seasons when adequate moisture provides ephemeral forage. Elevation of the southwestern desert, ranges from below sea level at the Salton Sea, California, to 1524 meters (5000 feet) on desert mountains in Arizona and the desert floor in New Mexico. Much of the desert area in Arizona ranges from 152 meters (500 feet) just east of Yuma to 853 meters (2800 feet) around Phoenix. The east central portion of Arizona ranges from 1067 to 1524 meters (3500 to 5000 feet) and southwestern New Mexico ranges from 1219 to 1524 meters (4000 to 5000 feet).

Precipitation ranges from below 7.5 centimeters (3 inches) in portions of the California desert, to 20.3 centimeters (8 inches) at Phoenix, to 30.5 centimeters (12 inches) at the highest elevations. Topography is extremely varied, ranging from broad, nearly flat valleys, to very steep, rocky mountains that project up directly from the desert floor, to rolling hills, and deeply incised canyons. Major uses made by the public of these lands are grazing, hunting and recreation, including camping, sightseeing and off-road vehicle use.

Three sites were located on a large ranch located approximately 16 kilometers (10 miles) south of Aguila, Arizona and 113 kilometers (70 miles) northwest of Phoenix, Arizona (see Figure 1). It was determined that a test site of 2331 hectares (9 square miles)--5 kilometers by 5 kilometers (3 miles by 3 miles)--would be an optimal size. Three test sites were established, each on a different topography and vegetation complex. Site 1 is located at the northern boundary of the ranch at the highest elevation on the desert floor, 658 to 719 meters (2160 to 2360 feet). This site represented rolling hills with a high predominance of gravel in the soils, outwash plains or bajadas with sandy loam soils, and a large, predominantly sandy area (including several broad desert ephemeral stream channels). Vegetation is predominantly creosote bush, white bursage, green bursage, paloverde and an assortment of cacti (see Figure 2). For a complete list of plants and their scientific names, see Appendix B (pages 208-209).

Site 2 is located just 3 kilometers (2 miles) south of Site 1 on a range of two steep desert mountains with shallow rocky soils separated by several narrow valleys. Elevation ranges from 597 meters (1960 feet) in the valleys to 866 kilometers (2840 feet) on the mountain tops. The mountains and valleys are deeply incised by drainage channels. Vegetation consists of a rich mixture of desert trees and shrubs (see Appendix A). Percent ground cover is

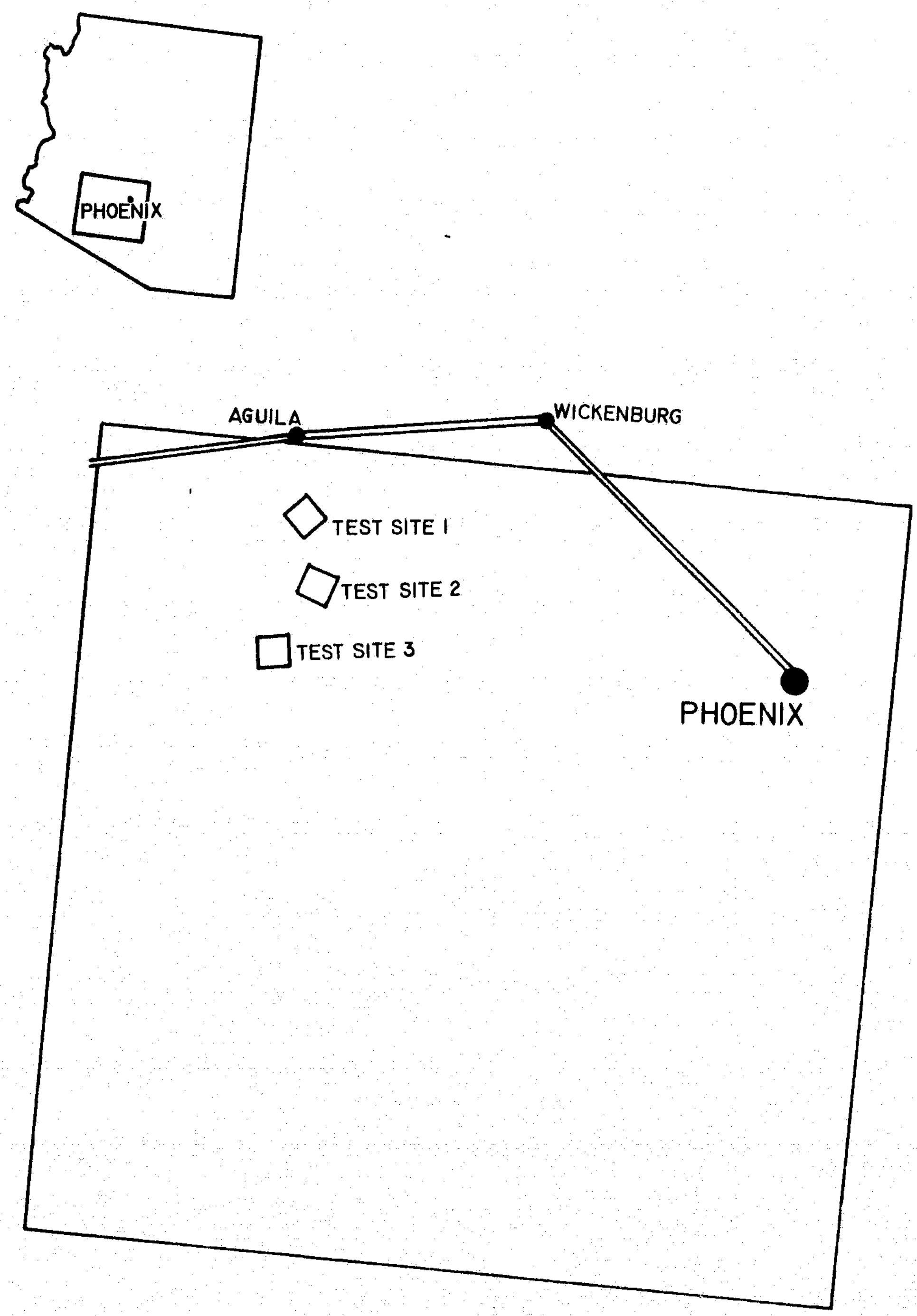
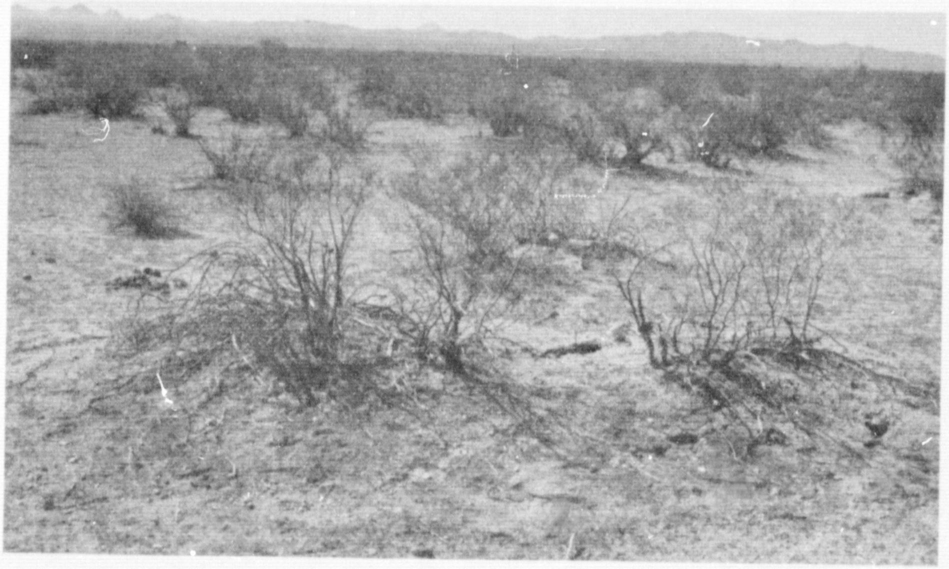


FIGURE 1. LOCATION OF EPHEMERAL RANGELAND SITES IN ARIZONA.



Site 1. View looking northeast across a gently sloping, flat outwash plain with a fairly open stand of creosote bush growing on a sandy loam soil.

Site 2. View looking at a steep, rocky, north-facing slope with a rich mixture of desert shrubs and trees.

FIGURE 2. GENERAL VIEW PHOTOS ILLUSTRATING TYPICAL TOPOGRAPHY, SOILS, AND VEGETATION FOR THE ARIZONA TEST SITES.

fairly constant at approximately 18 percent on all but one plant community. The mountains support much more green bursage and brittlebush than found on the desert floor.

Site 3 is located 6 kilometers (4 miles) southwest of Site 2 on the desert floor. This site is slightly more arid than the other two sites, which are located close to the Harquahala Mountains. Topography ranges from several steep volcanic mountains at 579 meters (1900 feet) elevation to low hills, outwash plains and sandy flats. Elevation on the areas away from the mountains range from 466 to 512 meters (1530 to 1680 feet). Soils are similar to those found on Site 1. Soils on the low hills are a very gravelly sandy loam, while soils on the outwash plains contain less gravel. The southwest portion of the site contains a large area of very sandy soils. Plant species are similar to those found on Site 1. The southwest portion of the site contains a large area of very sandy soils. Plant species are similar to those found on Site 1 (see Appendix A); however, this site contains a fair number of ironwood trees found only occasionally on Site 1, and a greater concentration of saguaro and paloverde.

1.4 Montana Test Area

Study sites were also chosen in Montana to give the study a good cross-section of the variety of rangeland managed by the BLM.

The Montana rangelands represent a more moderate climate producing perennial vegetative communities. Three sites were located approximately 96.6 kilometers (60 miles) south of Miles City, in the southeastern portion of Montana (see Figure 3). National resource lands are intermingled with the large concentration of privately owned rangelands. This land pattern increases management problems for the BLM. Elevation here ranges from about 762 to 1372 meters (2500 to 4500 feet). Topography varies from rolling hills covered with sage and grasses, narrow valleys and steep, pine covered mountains of sandstone and limestone. Soils range from sandy loam to clay loam. Precipitation ranges from about 33 to 41 centimeters (13 to 16 inches) per year, much of it coming as rain during the spring and summer; spring is generally wet, while summers are more dry.

Site 4 (Liscom Creek) is located on the northern boundary of the Custer National Forest, just east of the Tongue River. Topography ranges from rolling hills, narrow valleys and steep pine covered hills. Elevation ranges from 884 to 1097 meters (2900 to 3600 feet) and annual precipitation averages 40.6 centimeters (16 inches). Vegetation consists of a variety of grasses, forbs, shrubs (including silver sage, skunkbush and rose), and ponderosa pine (see Appendix B, pages 211-213).

Site 5 (Allen Ranch) is located 39 kilometers (24 miles) to the east of Site 4 and 10 kilometers (6 miles) east of Volborg, Montana, on Sand Creek. Site 5 is very similar in character to Site 4, except that the average precipitation is 33 centimeters

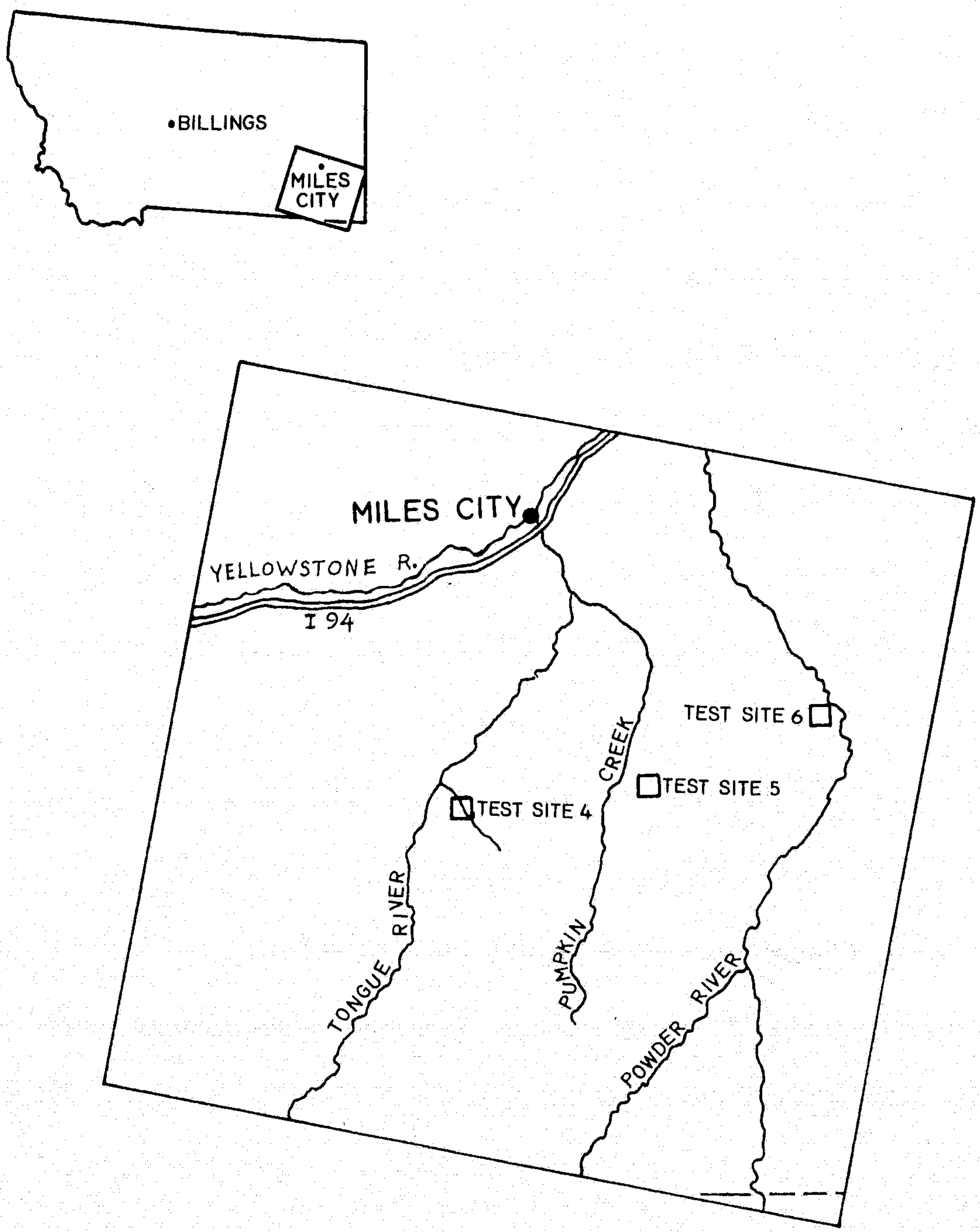


FIGURE 3. LOCATION OF PERENNIAL RANGELAND SITES IN MONTANA.

(13 inches) per year.

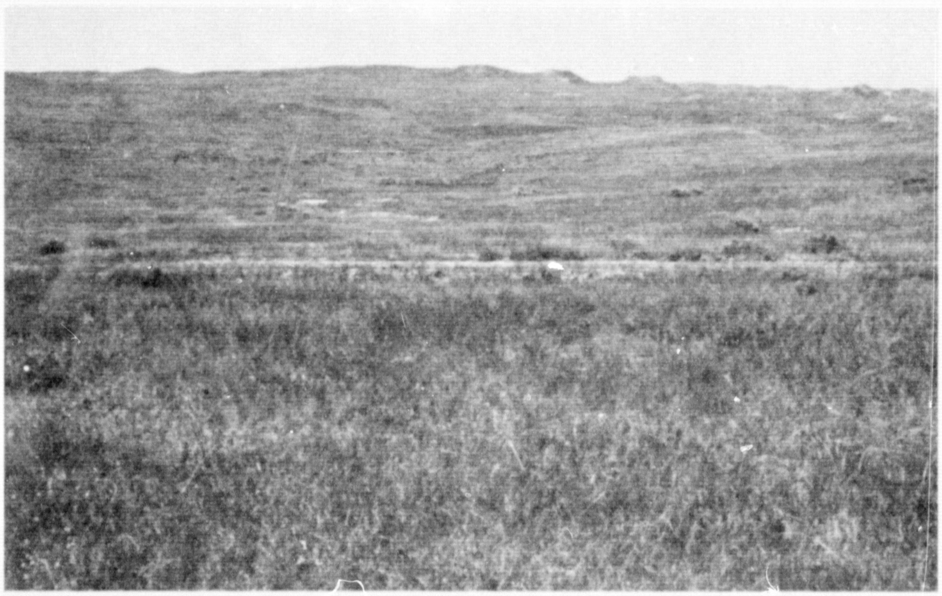
Site 6 (Scott Ranch) is located 19 kilometers (12 miles) north of Powderville and west of the Powder River along Ash Creek. Topography is rolling hills, some small buttes, long narrow valleys and several long broad valleys (see Figure 4). Elevation ranges from 884 to 975 meters (2900 to 3200 feet) and average annual precipitation is 40.6 centimeters (16 inches). Vegetation is made up of grasses, forbs, silver sage and greasewood (see Appendix B). Trees are confined to a few ash along major ephemeral drainage channels. Composition of plants in each plant community, by transect, is shown in Appendix A.

Field work was conducted at six times during the spring and summer. For brevity, these dates have been assigned identification numbers and will hereafter be referred to by number in this report (see Table 1).

TABLE 1. DATES OF FIELD WORK CORRESPONDING TO LANDSAT OVERPASSES.

Area	Reference	Field Work
Arizona	Date 1	04 April - 05 April 1975
Arizona	Date 2	10 May - 11 May 1975
Montana	Date 3	17 May - 18 May 1975
Montana	Date 4	02 June - 04 June 1975
Montana	Date 5	23 June - 24 June 1975
Montana	Date 6	31 July - 02 August 1975

Allen, Site 5. View looking east at ridgetop in the foreground, bluestem hillside, farmland, Upland grass, and finally pine-bunchgrass in the extreme background.



Scott, Site 6. View looking west at rolling hills grassland.

FIGURE 4. GENERAL VIEW PHOTOS ILLUSTRATING TYPICAL TOPOGRAPHY AND VEGETATION FOR THE MONTANA TEST SITES.

2.0 DATA COLLECTION

2.1 Field Method for Plant Community Data

Boundaries between plant communities were located in two ways. In Montana, color aerial photographs were taken of each of the three test sites using a Cessna 182 aircraft equipped with a Hasselblad 500 ELM camera and a 50 millimeter Zeiss Distagon lens mounted in the belly, following procedures outlined by Woodcock (1976). A mosaic of the color photographs was made and plant community boundaries were drawn on the mosaic by a photo interpreter. In Arizona, aerial photographs were not available. Plant community boundaries were charted on a Geological Survey standard 15 minute series quadrangle map during an aerial reconnaissance of the test site.

Percent composition of species and the percent of ground covered by live vegetation were measured for each plant community using the toe-pace transect as reported by Branson and Owen (1970), and as modified by BLM. Transects in Arizona were 300 paces long; transects in Montana were 100 paces long. The difference in length of transects reflects the density of plants found within a site. In Arizona the plants are sparse, widely scattered, and require a greater length of transect to get adequate data. In Montana the plants are much more dense and a shorter transect can be used.

Observations along the transect are made by sighting vertically at a notch cut in the toe of the boot of the observer. The notch is cut 3 millimeters (1/8 inch) wide and deep in the sole.

The observer records a hit on live vegetation when a portion of the plant is seen under the notch or obscures a view of it from above. The transect is paced in a straight line through a representative portion of each community at right angles to ridges or drainage patterns, except in Montana where narrow ridges were traversed in order to obtain adequate data. An observation is made at the end of each pace; a pace is two steps, or approximately 2 meters (6 feet). If no live vegetation is seen, a hit on bare ground is recorded. The number of hits on vegetation divided by the total number of hits determines the percent of ground covered by vegetation. Species composition within the plant community is determined by the number of hits for each plant divided by the total number of hits on live vegetation (see Appendix A).

Standard BLM vegetative mapping procedures were used to gather plant data for this study. The BLM requires that only basal area of grasses and forbs be recorded. This procedure gives percent ground cover which will remain constant during short periods of drought or above average precipitation. Perennial plant cover will change over a longer period if precipitation remains abnormal. For example, a prolonged drought for two or more years will reduce the percent ground covered by plants when computing ground cover on the basal area of plants. Percent ground cover is not computed on aerial grass parts (leaves and stems) because these are so variable. The amount of leaves and stems changes over time throughout the growing season or from season to season as a result of below or above average precipitation.

Based on BLM procedure, the percent vegetation cover of the test site was assumed constant for one season with only the phenology of each changing. Although such a procedure is appropriate for field studies, it was not optimal for a LANDSAT study. For purposes of this study it would have been better to have recorded aerial coverage of grasses and forbs. This would have increased the estimates of percent ground cover and percent of the total species composition made up by grasses and forbs. Such a sampling of the plant community would have more closely represented the scene as viewed by the satellite, which records all live vegetation. Basal area data does have the advantage that the data does not change throughout the growing season. This is helpful when using imagery for several different dates and manpower constraints allow collection of field data only one time. However, the aerial extent of the crown of shrubs and trees was recorded. In plant communities where shrubs or trees make up a significant percent of the total plant composition, crown measurements should closely reflect the data recorded by the satellite. Plant production was measured in Montana at the end of the growing season.

In Arizona, soil information was recorded to give assistance in determining what soil parameters could be observed on satellite data. Soil characteristics recorded were soil particle size (sand, silt or clay), surface rock and color (see Appendix B, page 210).

Greening curves for key plants in Arizona and Montana were developed from field observations during the year and through experience. The percent of green matter of each plant was plotted for the 1975 growing season and for an average year. This data illustrated how the ratio of green to dry matter changes as plants grow, flower, mature and become dormant or die. The average curve was used as a comparison, since the 1975 spring growing season in Arizona was very dry and in Montana was very wet and cold. The greening curves were used to provide the percent of green (enhancing chlorophyll absorption in the red) that each plant would contribute to the community during the season. These figures, when multiplied by the percent of the total plant community made up by a given species, give an approximation of percent green matter in the community.

2.2 LANDSAT Multispectral Data

LANDSAT data was available for three dates in Montana and two dates in Arizona. This allowed comparison and selection of the best data for recognition according to weather conditions, electronic noise, and plant phenology. Ideally, it would have provided comparison of processing results to determine how closely LANDSAT data corresponded with theoretical predictions of changes in vegetation. However, of the Montana data, one set was cloud-covered and one set arrived too late in the study to be of use. For Arizona, the data for both dates available had at least one channel which was too noisy to use. In addition, vegetation was so sparse that the contrast needed for vegetation studies was not available. As a result, only one data set for each locality was actually processed, although preliminary work was done on others. The following two frames were used:

Montana	E2152-17121	23 June 75
Arizona	E2118-17270	20 May 75

The three test sites chosen from each data set were mapped out on geometrically corrected base maps of LANDSAT data at a scale of approximately 1:18,000. All data used were corrected for atmospheric haze and electronic dropout noise. The data was not resampled to orient east-west. Local section lines were used to delineate the test areas in Montana. Since the test sites in Arizona were not chosen in uniform orientation, they are not necessarily presented so in this report; the direction of north is indicated on each figure.

The method of geometric correction used is accurate to within one pixel for sites as small as those used. A line is repeated at uniform intervals (the interval depending on the latitude) to make up for a small difference in aspect ratio between a LANDSAT resolution element (pixel) and a character on an IBM printer. Also, every fourth pixel is repeated, which adjusts the horizontal aspect ratio. This method of geometric correction is not too different in data quality from other methods of geometric correction which require the repetition of points to fit a specific scale or aspect. It is very efficient for printing graymaps on the IBM printer, as it does not require complete reformmating of data.

The spatial resolution of LANDSAT is nominally 79 meters (259 feet) on a side, with something under 30 percent overlap in pixels side-to-side. The presence of features smaller than one resolution element is often detected where spectral contrast is high. Spatial resolution becomes important in areas of high variability, such as in the three sites chosen in Montana.

2.3 Field Spectrometer Measurements

Spectral measurements in this program were made with the Bendix Aerospace Systems Division Radiant Power Measuring Instrument (RPMI) for LANDSAT groundtruth. This instrument is a rugged, accurately calibrated, field portable spectrometer capable of measuring both down-dwelling and reflected radiance in four spectral bands (typically configured for the four LANDSAT MSS channels) in the visible and near infrared. The relative response of the RPMI for each of these bands (LANDSAT channels 4, 5, 6, 7) is shown in Figure 5. Table 2 is a summary of the salient RPMI specifications.

The unit uses a transmissive diffuser to obtain a Lambertian, hemispherical, field of view (fov). Radiance measurements are made by installing a telescope tube over the diffuser and locking the tube in place. With the field of view thus restricted the telescope is vertically pointed at the object whose reflectance is to be measured. Each of the spectral bands 4 through 7 are then selected, via a switched turret band-pass filter followed by a silicon detector, and the meter readings are recorded. The broad band radiance may also be measured at this time.

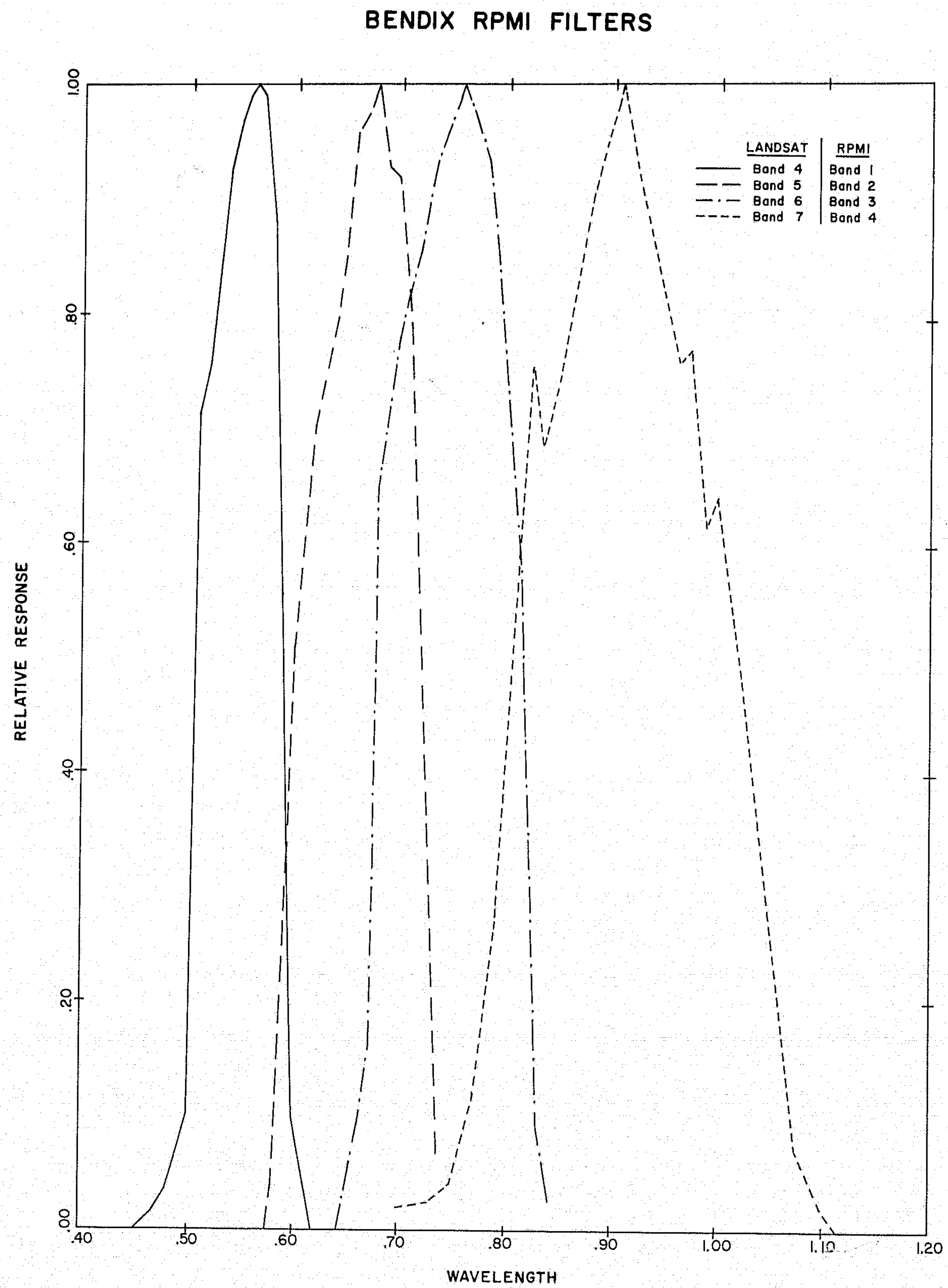


FIGURE 5. RELATIVE SPECTRAL RESPONSE OF BENDIX AEROSPACE SYSTEMS DIVISION RADIANT POWER MEASURING INSTRUMENT (RPMI).

TABLE 2. BENDIX RPMI SPECIFICATIONS.

Spectrometer Bands		LANDSAT Channels		Wavelength
1	-	4	-	0.5 to 0.6 microns
2	-	5	-	0.6 to 0.7 microns
3	-	6	-	0.7 to 0.8 microns
4	-	7	-	0.8 to 1.1 microns

Field of View is Selectable in Two Modes

Mode 1 provides 2 steradian fov through diffuser

Mode 2 provides 7.0° circular fov through telescope-handle

Sensitivity

12 range scales permit radiance measurements from 0.10 to 10^5 watts/(meter ^{2} . steradian)

Calibration

Absolute accuracy (traceable to NBS) of $\pm 5.0\%$ over operating ranges for period of greater than 1 year

Band to Band accuracy $\pm 2.0\%$

Repeatability $\pm 0.5\%$

Frequency Response

0 to 1.0 Hz on meter

0 to 20.0 Hz at BNC output (0 to +4 volts into 500 ohms)

Power and Environment

Two 9.0 volt batteries provide 50-100 hours operation

From $-20^{\circ}C$ to $+70^{\circ}C$

In the field data collection process the spectrometer was oriented so that the object to be measured was approximately 1 meter (3.28 feet) from the diffuser surface. Thus with the 7.0^{o} fov, a spot approximately 12 centimeters (4.72 inches) in diameter was typically measured. The RPMI was fixed to a tripod and the unit was pointed and leveled to view the object vertically and normal to the surface. Using the turret control each LANDSAT band was then selected and its radiance read on the meter and recorded on the data sheet (Figure 6). Having accomplished this, a Fiberfrax[1] panel was then placed in the same position occupied by the object and the new readings for each band on the Fiberfrax were recorded. During the early stages of the field measurements the Fiberfrax was recorded for each sample. However, with time and experience it was found that on a clear day the Fiberfrax could be recorded in approximately 30 minute intervals without major variations in the readings.[2] Using these two sets of readings a normalization process was used to calculate relative reflectance. Since each spectrum was reduced to spectral reflectivity with respect to this Fiberfrax standard, the measurements themselves are relatively free of atmospheric and sun angle bias. However, it should be noted that the LANDSAT pixel values and their standard

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[1]Fiberfrax is a white ceramic wool that has the unique characteristic of being renewable after contamination by peeling its surface layer and pressing the newly exposed surface flat.

[2]In truth, this is a rather "glib" assumption for many reasons, eg. variations in haze effects and cloud drift during the 30 minute cycle go unrecorded. However, in order to expedite the data collection, the operator was given instructions to use the 30 minute pattern when cloud cover was not present.

FIGURE 6. EXAMPLE OF DATA SHEET - RADIANT POWER MEASURING INSTRUMENT.

Date: 5/11/75 Site: Site C, Arizona Cloud Cover: 0% Observer: Bentley

Local Time	Measurement Location	Target Material	MSS Band 1	MSS Band 2	MSS Band 3	MSS Band 4
0924	Site C	Fiberfrax	0.0385	0.0350	0.0310	0.0225
0926	NE 1/4 NW 1/4 Sec 23	Black rocks/rocky soil	0.00503	0.00650	0.00610	0.00545
0928	T4N R10W	Black rocks/rocky soil	0.00560	0.00655	0.00630	0.00500
0931		Black rocks/rocky soil	0.00605	0.00620	0.00670	0.00525
0944		Fiberfrax	0.0460	0.0425	0.0380	0.0280
0948		Light and dark rocky soil	0.0069	0.0085	0.0083	0.0064
0950		Light and dark rocky soil	0.0080	0.0098	0.0095	0.0076
0952		Light and dark rocky soil	0.0077	0.0094	0.0092	0.0074
0944		Fiberfrax	0.0460	0.0425	0.0380	0.0280
0955		Large, black, shiny rock	0.0042	0.0050	0.0050	0.00445
0957		Large, black, shiny rock	0.0048	0.00555	0.00550	0.00485
0959		Large, black, shiny rock	0.0028	0.0032	0.0033	0.00325
0944		Fiberfrax	0.0460	0.0425	0.0380	0.0280
1005		Enfa	0.0080	0.0085	0.0116	0.0015
1007		Enfa	0.0084	0.0086	0.0130	0.0128
1009		Enfa	0.0056	0.0061	0.0079	0.0079

deviations are atmospheric- and sun angle-dependent. Thus, an attempt was made to gather data at high sun angles to minimize variations in reflected intensity.

Figure 6 is a typical field data sheet on which the field spectral radiance values were recorded for each reading taken. The radiance of the object in each band was divided by the radiance in the same band of the Fiberfrax. That number multiplied by 100 was then taken as the relative spectral reflectance; Figure 7 gives the computed spectral reflectance for each sample in Figure 6. These values were then averaged for like units, providing a single average reflectance for each of the four items in four spectral bands. Thus in Figure 7 we can note the following:

1. Black rocks/rocky soil corresponds to item 22.
2. Light and dark rocky soil corresponds to item 23.
3. Large, black, shiny rock corresponds to item 24.
4. Enfa corresponds to item 25.

The LANDSAT band average reflectances for the data collected in Arizona and Montana are given in Table 3.

FIGURE 7. EXAMPLE OF COMPUTED RELATIVE SPECTRAL REFLECTANCE.

MSS Band / Object	% Relative Spectral Reflectance			
	4	5	6	7
Black rocks, rocky soil	13.06 14.55 15.71	18.57 18.71 17.71	19.68 20.32 21.61	24.22 22.22 23.33
Light and dark rocky soil	15.00 17.39 16.74	20.00 23.06 22.12	21.84 25.00 24.21	22.86 27.14 26.43
Large, black, shiny rock	9.13 10.43 6.09*	11.76 13.06 7.53	13.16 14.47 8.68	15.89 17.32 11.61
Enfa	17.39 18.26 12.17	20.00 20.24 14.35	30.53 34.21 20.79	41.07 45.71 28.21
*Measurement made on vesicular rock				

TABLE 3. LANDSAT FIELD SPECTRA OF INDIVIDUAL MATERIALS.

Chan 4	Chan 5	Chan 6	Chan 7	*I.D. No.	Date	Name
10.80	10.32	38.57	55.13	40101	060475	Rhtr
07.73	07.53	36.94	56.80	40101	062475	Rhtr
06.55	06.66	24.80	38.36	40101	080175	Rhtr
10.94	10.96	24.84	37.14	40102	051775	Artr
11.88	14.01	29.32	41.22	40102	060475	Artr
08.99	08.63	24.27	36.67	40102	062475	Artr
10.41	12.09	19.96	27.23	40102	080175	Artr
11.51	11.58	27.11	44.63	40103	051775	Arca
10.94	10.32	31.04	44.55	40103	060475	Arca
09.44	09.14	27.47	41.77	40103	062475	Arca
08.15	09.17	18.96	27.55	40104	051775	Trdu
11.02	10.48	37.59	53.91	40105	060475	Syoc
07.18	06.55	25.60	38.63	40105	062475	Syoc
08.75	08.21	28.26	41.70	40105	080175	Syoc
18.73	19.29	41.91	54.49	40106	080175	Atco
07.37	06.78	30.27	45.69	40107	062475	ASTRA
17.03	25.59	29.69	34.29	40201	051775	Red-white soil (moist)
32.32	43.91	49.60	54.51	40201	062475	Red-white soil (moist)
28.88	38.81	43.16	49.07	40201	080175	Red-white soil (moist)
23.75	34.24	41.13	50.29	40202	051775	Small red rock pavement
18.75	26.11	29.23	32.34	40202	060475	Small red rock pavement
21.04	29.71	34.43	38.61	40202	062475	Small red rock pavement
17.02	23.55	27.75	31.18	40202	080175	Small red rock pavement
30.63	45.09	44.91	63.43	40203	051775	White soil
35.65	41.27	42.07	43.41	40203	060475	White soil
37.17	42.99	46.14	51.57	40203	062475	White soil
43.44	48.17	49.47	54.85	40203	080175	White soil
35.00	46.44	49.81	52.00	40204	051775	Large red sandstone
23.19	31.75	36.55	41.46	40205	060475	Yellow sandstone cobble
22.45	31.65	38.11	44.69	40205	080175	Yellow sandstone cobble
26.38	34.92	36.21	37.07	40206	060475	Large yellow sandstone rock
26.39	35.32	39.37	42.81	40206	080175	Large yellow sandstone rock
21.62	30.80	36.80	43.14	40208	062475	Orange cobble
14.14	18.39	20.80	20.59	40209	062475	Red-purple rock
09.38	10.05	24.62	37.65	40210	062475	Atco
11.56	12.27	26.30	38.66	40210	080175	Atco
27.96	39.56	44.21	47.60	40211	062475	Red-orange rock
11.74	13.83	18.86	26.22	40301	051775	Bogr (dry)
10.75	12.57	20.93	26.17	40301	060475	Bogr (dry)
09.84	11.11	21.12	28.88	40301	062475	Bogr (dry)
11.93	14.14	21.92	19.15	40301	080175	Bogr (dry)
15.53	18.67	26.58	37.20	40302	062475	Litter, bare ground
18.08	22.58	28.67	37.19	40302	080175	Litter, bare ground
06.80	07.67	17.37	28.40	40303	062475	Agsm
09.62	12.04	19.52	28.42	40303	090175	Agsm
10.98	11.44	32.10	51.11	40401	051775	Pipo
10.13	10.11	32.77	44.79	40401	062475	Pipo
09.60	09.45	26.87	43.79	40401	080175	Pipo
07.86	08.44	19.74	28.80	40501	062475	Kocr
12.03	15.17	20.00	24.37	40501	080175	Kocr

TABLE 3. CONTINUED

Chan 4	Chan 5	Chan 6	Chan 7	*I.D. No.	Date	Name
10.19	12.04	17.01	22.67	40502	051775	Cafi
08.31	08.84	20.40	28.61	40502	062475	Cafi
11.97	14.50	19.30	24.51	40502	080175	Cafi
14.68	18.94	23.61	28.22	40503	062475	Red lichen covered rock
16.97	21.39	25.13	28.28	40503	080175	Red lichen covered rock
10.52	10.29	22.95	30.70	40504	062475	Calo
10.25	10.50	19.63	26.04	40504	080175	Calo
08.94	10.56	15.25	20.35	40601	051775	Pose, Stco, Brte, Arlo
11.38	12.57	21.87	28.94	40601	060475	Pose, Stco, Brte, Arlo
06.83	07.15	22.09	36.53	40601	062475	Pose, Stco, Brte, Arlo
09.35	10.99	26.04	41.23	40601	080175	Pose, Stco, Brte, Arlo
13.45	15.73	27.50	38.18	40602	080275	Stco
14.81	16.79	29.86	13.13	40603	080275	Arlo
11.37	11.71	22.68	30.59	40604	080275	Bocu
09.18	12.28	14.42	17.25	40605	051775	Ansc
09.94	16.40	17.23	20.53	40605	060475	Ansc
07.76	09.44	14.84	19.17	40605	062475	Ansc
08.03	09.88	20.49	29.80	40605	080175	Ansc
06.88	09.20	18.14	25.72	40606	051775	Agsp
07.94	08.11	23.45	35.22	40606	060475	Agsp
09.00	09.50	20.68	29.31	40606	062475	Agsp
10.47	12.84	19.14	25.42	40606	080175	Agsp
08.03	08.57	25.10	38.45	40701	051775	Taof
07.85	08.91	29.06	45.52	40701	060475	Taof
06.88	07.01	28.36	43.41	40701	062475	Taof
07.65	10.27	24.70	51.06	40701	080175	Taof
28.80	35.60	37.53	39.64	40801	051775	Light soil (dry)
25.51	35.36	37.93	40.49	40801	060475	Light soil (dry)
18.00	29.23	35.80	37.14	40802	051775	Light reddish soil (wet)
19.69	30.70	37.59	43.53	40802	062475	Light reddish soil (wet)
19.09	31.19	38.46	45.56	40802	080275	Light reddish soil (wet)
21.00	30.99	32.93	40.18	40803	051775	Light reddish soil (dry)
32.00	47.28	54.97	63.87	40803	060475	Light reddish soil (dry)
26.14	37.02	36.45	49.03	40803	080275	Light reddish soil (dry)
36.91	44.52	48.90	42.88	40804	051775	Milk-white soil
42.28	48.45	48.24	57.32	40804	060475	Milk-white soil
37.59	48.00	43.75	44.71	40804	062475	Milk-white soil
50.40	59.15	62.99	64.68	40804	080275	Milk-white soil
25.27	31.55	34.00	38.39	40805	060475	Dark gray soil
17.84	22.58	25.09	28.78	40805	062475	Dark gray soil
19.96	24.50	30.28	31.74	40805	080175	Dark gray soil
07.36	06.29	47.06	78.57	40901	060475	Alfalfa
07.29	05.97	03.46	05.08	40901	051775	Alfalfa
06.05	05.25	37.80	68.50	40901	062475	Alfalfa
06.21	06.31	30.25	30.44	40901	080275	Alfalfa
07.45	06.39	33.65	57.14	40902	060475	Hayfield (rye)
04.32	03.38	25.09	39.50	40902	062475	Hayfield (rye)
21.49	28.06	31.07	31.00	50101	051875	Light rocky soil
12.99	18.47	22.05	24.38	50102	051875	Dark gravelly soil
10.30	11.72	16.96	20.92	50103	051875	Agsp

TABLE 3. CONTINUED

Chan 4	Chan 5	Chan 6	Chan 7	*I.D. No.	Date	Name
09.63	10.14	18.75	24.44	50103	062475	Agsp
09.47	11.24	17.70	25.14	50103	080175	Agsp
07.78	08.09	20.63	29.33	50104	062475	Kocr
08.89	10.89	18.13	23.12	50104	080175	Kocr
36.99	41.93	45.21	49.02	50105	062475	Dark soil
21.69	25.38	29.65	40.56	50105	080175	Dark soil
36.79	43.62	46.17	35.73	50106	062475	Reddish soil
23.01	28.51	31.03	33.90	50107	062475	Tan outcrop
12.54	16.25	22.79	32.28	50108	062475	Dark bare soil
13.10	18.25	23.10	24.68	50108	080175	Dark bare soil
29.80	38.08	44.06	48.00	50109	062475	Light soil, sedge
07.90	08.77	17.66	24.44	50110	062475	Cafi
39.06	45.80	48.57	47.85	50201	051875	Cream-colored soil
25.00	32.34	35.32	38.75	50201	060475	Cream-colored soil
38.46	48.01	52.28	59.49	50201	080175	Cream-colored soil
34.01	38.79	42.18	44.94	50202	051875	Light gray-white soil
06.75	07.63	22.27	30.64	50301	051875	Juho
05.58	05.35	20.47	27.54	50301	062475	Juho
09.33	09.04	26.40	36.90	50301	080175	Juho
10.57	10.18	25.42	34.74	50302	051875	Artr
09.62	09.57	21.73	22.93	50302	062475	Artr
08.79	10.05	17.89	27.22	50302	080175	Artr
09.27	08.65	21.48	29.29	50303	051875	Arca
13.77	14.04	31.25	42.00	50303	062475	Arca
06.64	06.14	30.11	46.78	50304	062475	Rhtr
06.49	07.31	25.62	43.33	50304	080175	Rhtr
05.84	06.83	17.47	26.10	50305	062475	Yugl
12.02	12.99	36.40	48.40	50305	080175	Yugl
09.51	10.03	21.93	29.69	50401	051875	Agsm, Bogr, Brte
10.37	11.22	16.98	16.92	50402	051875	Agsp
09.33	10.66	15.94	18.33	50403	060475	Bogr
10.74	11.84	20.79	28.69	50403	062475	Bogr
10.16	12.24	26.08	36.65	50403	080175	Bogr
16.52	21.60	25.03	25.39	50404	060475	Dark rocks, light soil
27.04	24.49	39.53	33.08	50405	060475	Light soil
24.37	28.50	33.11	33.52	50405	062475	Light soil
33.49	43.72	49.65	56.42	50405	080175	Light soil
10.09	11.22	16.98	16.92	50406	060475	Cafi
11.94	15.12	23.34	30.60	50406	080175	Cafi
08.47	08.37	24.76	37.89	50408	062475	Arfr
06.76	06.24	20.17	31.46	50501	062475	Agsm, Stco
07.12	08.43	14.19	21.09	50502	062475	Ansc
05.82	07.20	15.80	20.99	50502	080175	Ansc
09.55	09.66	25.46	36.98	50503	062475	Trdu, Agsp
10.49	11.50	28.67	40.30	50503	080175	Trdu, Agsp
27.47	36.67	39.60	38.24	50504	080175	Large yellow sandstone rock
06.70	08.64	15.92	22.59	50505	080175	Agsm
07.83	08.60	20.43	29.69	50601	060475	Pose, Bogr (short green)
08.71	09.11	24.65	38.73	50601	062475	Pose, Bogr (short green)
21.84	27.00	30.12	34.26	60101	060275	Bare soil

TABLE 3. CONTINUED

Chan 4	Chan 5	Chan 6	Chan 7	*I.D. No.	Date	Name
24.40	30.45	33.41	36.61	60101	062375	Bare soil
09.69	11.10	16.90	22.30	60102	060275	Kocr, Cafi, soil
09.17	10.52	16.33	21.58	60102	062375	Kocr, Cafi, soil
10.19	11.36	18.90	27.11	60102	073175	Kocr, Cafi, soil
08.47	09.20	20.92	29.84	60103	060275	Yugl
08.49	09.37	23.46	34.91	60103	062375	Yugl
10.00	10.94	25.31	36.67	60103	073175	Yugl
07.53	07.27	25.19	38.68	60104	062375	Glle
14.27	25.16	28.40	33.59	60105	062375	Buff rock
10.15	12.66	18.07	24.24	60106	073175	Agsp, soil
22.00	27.92	32.05	37.78	60107	073175	Yellow sandstone rock
16.83	23.82	27.53	34.00	60108	073175	Sandstone lichen rock
07.03	07.83	15.32	22.13	60201	060275	Agsm, Brte
06.97	07.54	17.07	24.80	60201	062375	Agsm, Brte
07.89	09.03	21.73	33.73	60201	073175	Agsm, Brte
08.35	08.00	26.06	39.34	60202	060275	Arca
11.51	11.61	27.40	38.24	60202	062375	Arca
14.71	15.00	33.28	56.83	60202	073175	Arca
33.15	39.79	44.39	48.42	60203	062375	Light soil
25.77	31.34	34.41	38.64	60203	073175	Light soil
31.11	37.68	41.95	47.02	60204	062375	Dark soil
08.80	09.53	30.58	39.35	60301	060275	Bogr (short green)
08.45	09.12	23.96	35.38	60301	062375	Bogr (short green)
09.19	10.42	25.41	38.53	60301	073175	Bogr (short green)
09.35	09.68	29.76	45.26	60302	062375	Bogr (short), Taof
08.38	08.85	22.84	34.24	60401	060275	Agcr (seeded pasture)
07.35	07.53	22.11	32.58	60401	062375	Agcr (seeded pasture)
29.01	34.00	35.73	38.75	60402	060275	White bottom soil
34.17	40.19	38.48	41.20	60402	062375	White bottom soil
32.00	37.55	40.27	43.90	60402	073175	White bottom soil
16.58	25.20	29.44	29.38	60501	060275	Orange cobble rock
19.64	26.60	29.44	30.31	60502	060275	Yellow-orange cobble
20.06	22.87	24.19	26.04	60503	060275	Bentonite
14.23	27.60	30.00	32.14	60503	062375	Bentonite
15.98	18.53	19.93	21.02	60502	073175	Bentonite
19.66	26.40	30.12	31.81	60504	062375	Tan cobbled pavement
43.25	49.50	54.03	57.05	60505	062375	White soil
23.42	31.80	35.63	36.39	60506	062375	Reddish rock
14.39	20.21	23.18	23.39	60507	073175	Red rock pavement
19.91	27.58	30.00	31.19	60508	073175	Large yellow sandstone rock
19.70	26.79	30.18	32.19	60509	073175	Yellow rock pavement
08.92	08.93	20.23	28.23	60601	060275	Artr
09.07	09.00	21.89	31.15	60601	062375	Artr
10.14	11.26	19.65	27.24	60601	073175	Artr
08.29	09.30	16.30	22.03	60602	060275	Agsp
06.39	06.87	14.84	21.44	60602	062375	Agsp
09.03	09.71	23.35	33.73	60602	073175	Agsp
20.06	29.59	33.26	38.41	10101	051075	Sandy ground
20.18	25.92	27.98	30.26	11301	051075	Rocky soil
11.24	13.13	14.38	18.98	11302	051075	Frdu (dry)

TABLE 3. CONCLUDED

Chan 4	Chan 5	Chan 6	Chan 7	*I.D. No.	Date	Name
07.19	08.98	12.47	16.53	11303	061075	Latr (open)
21.09	22.34	24.88	29.01	10201	051075	Soil (dry) and annuals
09.62	10.38	12.12	15.08	10202	051075	Frde (dry)
04.28	04.48	12.85	15.46	10203	051075	Latr (dense, green)
27.48	34.48	37.69	43.65	10601	051075	Rocky soil
10.75	13.08	21.54	29.81	10602	051075	Cemi
07.66	12.18	18.67	36.88	20201	051075	Rock and soil
06.93	09.82	16.29	24.87	20202	051075	Frde (healthy)
05.43	08.12	15.48	26.22	20203	051075	Enfa
04.21	05.70	11.81	20.14	20204	051075	Frde
08.04	10.91	19.76	33.94	20205	051075	Frdu
10.34	13.77	15.32	15.68	20301	051075	Purple rocky soil
10.89	13.02	14.57	18.46	20301	051175	Purple rocky soil
05.93	07.73	25.50	29.31	20201	051075	Rocky soil
17.78	23.30	25.27	26.36	20201	051175	Rocky soil
16.94	21.70	23.49	25.64	20101	051075	Rocky soil
18.68	26.20	30.55	38.41	20101	051175	Rocky soil
07.46	07.28	30.05	52.38	21301	051175	Prju (green)
14.44	18.33	20.54	23.46	31301	051175	Rocky soil, black rock
16.38	21.73	23.68	25.48	30501	051175	Light and dark rocky soil
08.55	10.78	12.10	14.93	30503	051175	Black rock (large, shiny)
15.94	18.20	29.51	38.33	30502	051175	Enfa
23.33	30.61	34.76	40.86	30201	051175	Sandy wash
22.07	29.91	34.76	46.04	30801	051175	Sandy gravelly soil
15.48	17.38	33.57	57.80	30802	051175	Frdu (healthy)
21.45	24.17	35.82	44.29	31201	051175	Sandy loam soil

*Left first digit of I.D. No. indicates site number of location.

3.0 APPROACH

3.1 Views of Vegetation Information in LANDSAT Data

When plant communities are considered as "target" areas, each is treated independently. The physical basis for spectral differences among targets is not usually analyzed. The vegetative or soil characteristics which are most influential in the spectral signature do not necessarily become apparent. As a result, the physical relationship of one plant community (soil color, major vegetative types, etc.) to another is not obvious in automatic recognition maps. The heterogeniety of one plant community or the gradation of two plant communities into one another can result in redundant classes or errors due to insufficient sampling.

Whether a plant community is recognizable in a particular data set because of differences in soil, plant species, or vegetation cover is not evident when employing automatic recognition. This can be a drawback, since the ability to recognize these same plant communities in another data set or in another area is contingent on which of these factors contributes most to its uniqueness. This difficulty led to a second approach to recognition processing--that of separation by important physical parameters. Just as land use studies with LANDSAT data often interpret the recognition classes in terms of cover types, rangeland mapping can also be done in terms of continuous variables, such as percent vegetation, percent grass, grass/shrubs within vegetation, etc.. There are a limited number of physical parameters to which LANDSAT is sensitive, even with registration of multiple-date data sets.

It is the signficance of those physical parameters to the definition of important plant communities that will determine the success of the signature approach in recognizing plant communities. To this end, the plant communities were evaluated in terms of physical characteristics to determine those which could be mapped with LANDSAT.

Some of the subtle, but significant, differences between automatic recognition mapping and mapping physical parameters with special functions are:

1. Special function mapping yields a continuous-tone image which can be used to infer the identity of additional areas in the scene (areas which are not very similar to any of the training set plant communities). Conversely, areas spectrally dissimilar from targeted plant communities would simply be listed as "unclassified" by an automatic recognition map.
2. Special function mapping relates one plant community training site to another by physical similarities.

Field data and field spectra were used to predict optimal combinations of LANDSAT data for mapping vegetation types. Where field spectra were used, the data set was called "theoretical". In addition, spectral data was extracted from the LANDSAT computer-compatible tapes (CCT's) resulting in what was termed the "empirical" data set and was processed in parallel with the theoretical data set. Two methods of supervised automatic recognition were applied using the empirical data. The flow chart in Figure 8 shows the coordinated theoretical and empirical processing activities leading to the maps produced for this report.

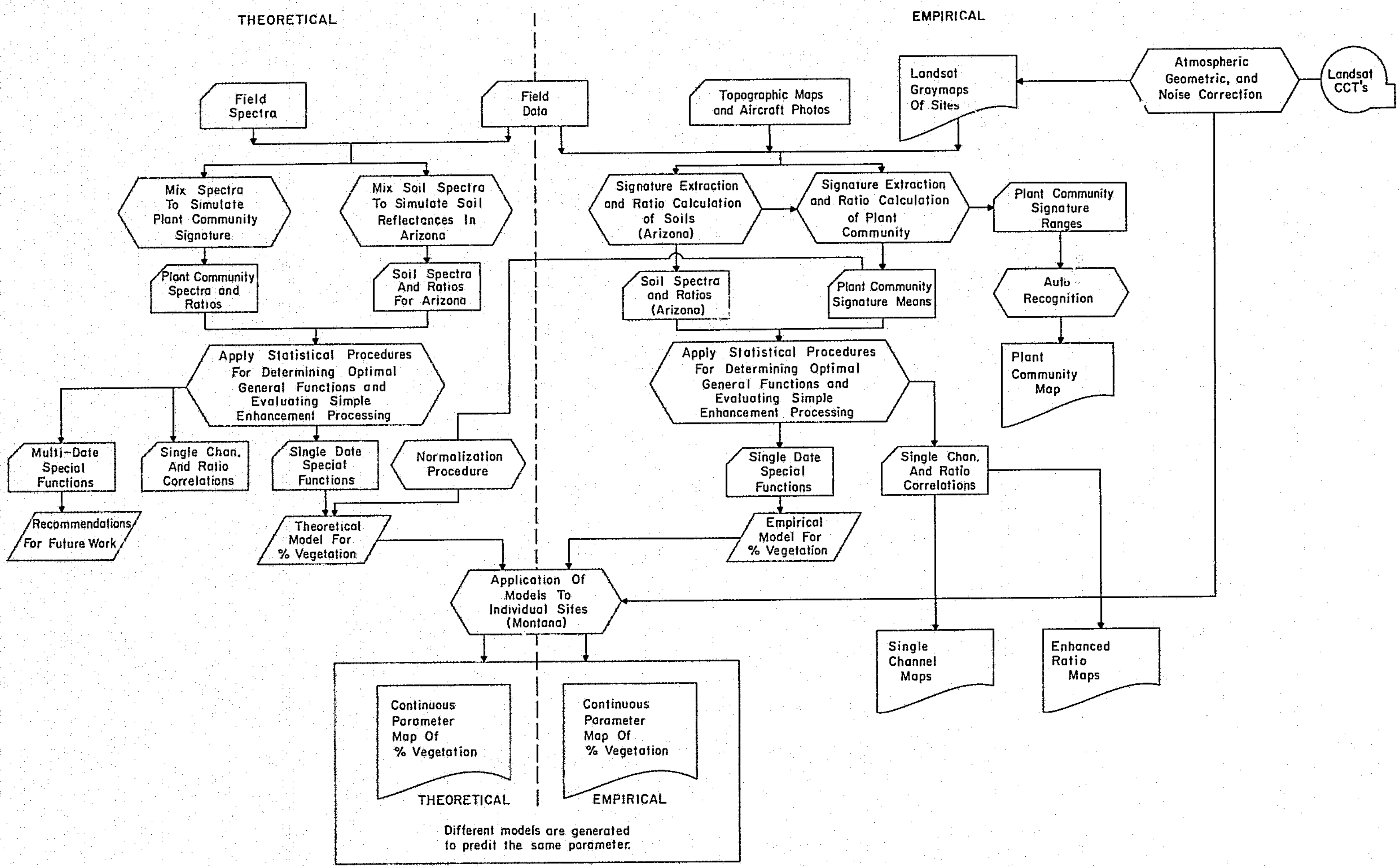


FIGURE 8. FLOW OF COORDINATED COMPUTER PROCESSING OF LANDSAT DATA.

3.2 Atmospheric and Solar Illumination Effects

From satellite altitudes, spectral path radiance caused by atmospheric scattering [L_λ(path)] cannot generally be neglected. When the L_λ(path) term is neglible, such as it can be for scanner data collected by low altitude aircraft on a clear, dry day, environmental factors can be considered multiplicative (Turner, Malila, Nalepka, 1971). If the additive L_λ(path) term can be suitably eliminated from satellite data, a multiplicative atmospheric correction can be applied to LANDSAT data. Under high visibility conditions, one can make empirical subtractions to a scene referred to here as <u>dark object subtraction</u>.

A dark material in shadow will have signal levels resulting from L_λ(path) and reflected diffuse irradiance, approximating the lowest possible radiance in the scene. For a given spectral channel, the value of the lowest radiance measured within the scene can be subtracted from all other spatial resolution elements to approximately correct for path radiance. If all channels or bands of a multispectral scanner are assumed to be spectrally narrow in the 0.4-2.5 μm wavelength region, the radiance in the i-th channel can be given by

$$L(i) \approx L_{\lambda_i} \Delta\lambda i \qquad (1)$$

where λ_i is the median wavelength and $\Delta\lambda_i$ is the spectral width (at 50% response points) of the i-th channel (Vincent, Salmon, Pillars, Harris, 1975).

On a clear day of 23 kilometers (14.29 miles) visibility

(Turner, Malila, Nalepka, 1971), the direct irradiance of the sun impinging on a target [E_λ(direct)] is approximately 2.7 times larger than the diffuse spectral irradiance of solar radiation incident on the target from directions other than from the sun to target direction [E_λ(diffuse)] at a wavelength of 0.55 microns. For longer wavelengths of light, particularly those greater than 0.7 micron wavelength, the illumination term is much more predominant. The smaller the diffuse illumination term, the smaller effect it has on the LANDSAT MSS signal and the less it will contribute to variations due to topographic differences in the single channel values. Differences in the signal seen in two areas with the same spectral reflectance can now be considered predominantly due to differences in the direct irradiance as a result of sun angle or topography.

A full discussion of the ratio processing techniques is available in a previous NASA report (Vincent, Salmon, Pillars, Harris, 1975) and will not be included here. However, a major reason for using spectral ratioing methods in our processing of LANDSAT data is to supress the spectral variations in direct irradiance which are not related to surface composition. As in single channels, the smaller the diffuse radiance term, the less effect topographic variations have on ratios of two channels of data. From Vincent, Salmon, Pillars, and Harris (1975), after dark object subtraction the ratio of two channels $R_{(i,j)}$ results in:

$$R_{(i,j)} = \frac{E\lambda(\text{sun},i)\,\tau(i)\;\rho(i)}{E_\lambda(\text{sun},j)\,\tau(j)\;\rho(j)} = \left(\frac{1}{K_{(i,j)}}\right)\frac{\rho(i)}{\rho(j)} \qquad (2)$$

where τ is the atmospheric transmittance, E_λ (sun,i) is the solar illumination, and ρ is the spectral reflectance of the target. Assuming E_λ (sun,i) approximately equals E_λ (sun,j), and that the channels are sufficiently close that τ (i) and τ (j) do not differ greatly, $R_{i,j} = [1/K_{(i,j)}]\, \rho(i)/\rho(j)$, which is dependent only on the spectral characteristics of the target material. The $R_{i,j}$ ratio, therefore, is much more independent of topographic variations across the scene than is the single channel radiance of the same data. Ratios of LANDSAT data will be referred to according to MSS channels 4-7, where i = numerator channel and j = denominator channel. $R_{i,j}$ designated as $R_{7,5}$ will mean MSS channel 7 divided by MSS channel 5, etc..

Although $R_{i,j}$ is relatively invariant with topographic changes across the scene, it still may not be invariant for a given type of target in two data sets collected at different times in different places. For a further suppression of environmental factors [E_λ (sun,i), τ(i), and L_λ (path, i)], one can use the spectral ratio of a known target to normalize to an area within the scene:

$$(R_{i,j})_{\text{ref.}} = \frac{E_\lambda(\text{sun},i)\,\tau(i)}{E_\lambda(\text{sun},j)\,\tau(j)} \left(\frac{\rho(i)}{\rho(j)}\right)_{\text{ref.}} = \left(\frac{1}{K_{(i,j)}}\right) \left(\frac{\rho(i)}{\rho(j)}\right)_{\text{ref.}} \qquad (3)$$

Division of Equation 2 by Equation 3 yields, after rearrangement, the corrected ratio:

$$R^{c}_{i,j} = \frac{R_{i,j}}{(Ri,j)_{\text{ref.}}} \left(\frac{\rho(i)}{\rho(j)}\right)_{\text{ref.}} = \frac{\rho(i)}{\rho(j)} \qquad (4)$$

which is equal to the spectral reflectance ratio of the target, almost independent of environmental factors. The "almost" is included in the foregoing statement because the degree of environmental independence is a function of how well the dark object subtraction succeeds in suppressing the path radiance term. If shadows are present over materials of varying brightness, a more rigorous determination of L_λ (path) can be made, but with greater difficulty (Piech and Walker, 1974).

The use of a known reflectance value for calibration of a particular data set is described herein as ratio normalization. This procedure does not help discrimination among targets on a relative basis within a single data set, but it is useful for extending recognition results in time and space. Normalization is necessary for any absolute value determinations using reflectance values from laboratory spectra as training sets.

3.3 Empirical Approach from Extracted LANDSAT Data

LANDSAT data were printed out in IBM printer format for preliminary location and correlation of field data. Ten levels of signal were designated by symbols chosen to best appear as gray-tones on the map. Map levels were set according to the distribution of values of data in the scene (derived from a histogram of population versus digital level) for optimal contrast and therefore were not necessarily optimal for depicting particular features of interest. However, the good contrast did allow recognition of physical features for location of field sites. Maps of LANDSAT channel 5 and $R_{7,5}$ were first used for location of each transect taken in the field. From these areas, a set of pixels composing a target, or training set, were defined. The digital levels of those points were read from the data and single channel values and ratios (after dark-object subtraction) were calculated for each pixel. These were then averaged to find the mean for each training set, and the range of each target group (all the training sets for a given target class) was recorded for each of the ten spectral parameters.

The ability to recognize with LANDSAT data the individual plant communities specified in the field data is dependent on:

1. Accurate location of the representative site chosen.
2. Inaccurate sampling due to pixels which overlapped more than one plant community.
3. How representative the chosen pixels are of the total plant community on which you are training.
4. Spectral uniqueness of the spectral features of any plant community within the spectral configuration of LANDSAT.
5. Variability of the spectral signature of the plant community, and the uniqueness and range of any spectral parameter in relation to the full dynamic range.
6. Variability in the data due to noise.

In Montana, transect data were collected along ridges and in valleys where broad, uniform vegetation stands were scarce. Location of representative pixels was sometimes difficult, causing some pixels to be mislocated into other plant communities. Training sets for the areas crossed by transects in the field ranged between 1 and 4 pixels for 26 plant communities in Montana. This is a relatively small number of samples on which to base a signature. Increased numbers of pixels chosen for each plant community resulted in broader ranges for at least some of the communities and partially reduced their uniqueness.

Where sampling is restricted to transect locations, stringent assumptions are made. Points must be located precisely and they must be truly representative of the plant community expected. In no way does this imply that the full variability of that plant community has been sampled, which may later affect recognition and mapping in other areas of the scene. Next, if one pixel is chosen to estimate the spectral characteristics of plant community A and four pixels are chosen to represent those of plant community B, clearly B is likely to have a larger apparent variability due to natural variety, electronic noise, imprecise location, etc. The mean value and range were determined for targets from each different plant community from extracted data of LANDSAT. Tables 4 and 5 show the means for each plant community. The data and site of each signature have been encoded according to the site, plant community, and date by number. In addition to the actual species make-up for each, percent vegetation cover and percent grass were recorded for sites in Montana. Percent vegetation cover and percent creosote bush were noted for sites in Arizona. Table 6 shows regrouping of the extracted data values into groups determined by soil types for Arizona. Soil types were numbered 1 to 23; additionally, they correspond to the soil maps according to the

TABLE 4. EMPIRICAL PLANT COMMUNITY SIGNATURE MEANS AND RATIOS EXTRACTED FROM LANDSAT DATA FOR MONTANA TEST SITES.

Chan 4	Chan 5	Chan 6	Chan 7	$R_{5,4}$	$R_{6,4}$	$R_{6,5}$	$R_{7,4}$	$R_{7,5}$	$R_{7,6}$	Site	P.C.	Date	% Veg.	% Grass
23.6	26.0	42.0	19.6	1.360	2.476	1.810	1.280	.940	.513	5	7	5	58	30
23.3	27.6	44.3	20.3	1.506	2.686	1.780	1.353	.896	.500	5	8	5	63	32
20.0	22.0	42.5	19.0	1.465	3.340	2.280	1.650	1.120	.490	5	9	5	59	19
22.0	23.5	42.5	18.5	1.340	2.820	2.095	1.355	1.005	.475	4	1	5	52	22
24.3	28.6	47.6	20.6	1.473	2.716	1.833	1.276	.863	.466	4	2	5	15	02
22.5	23.0	47.0	21.5	1.280	3.055	2.420	1.530	1.210	.495	4	3	5	46	31
21.0	22.0	39.0	16.5	1.540	2.765	2.060	1.295	.965	.465	4	4	5	57	19
22.6	26.3	42.3	19.0	1.483	2.660	1.793	1.316	.890	.490	4	5	5	32	24
21.3	25.3	43.6	20.0	1.576	3.073	1.946	1.546	.983	.500	4	6	5	47	38
21.3	21.3	54.0	26.0	1.263	3.946	3.123	2.056	1.626	.520	4	7	5	53	25
28.7	37.5	53.7	23.2	1.592	2.415	1.517	1.125	.705	.460	4	8	5	16	12
18.0	19.5	58.5	30.5	1.095	5.830	3.900	3.275	2.190	.560	4	9	5	70	35
25.0	30.0	44.5	19.5	1.495	2.405	1.600	1.150	.770	.480	5	1	5	43	21
25.5	32.5	47.5	20.7	1.600	2.520	1.570	1.197	.747	.470	5	2	5	16	07
21.0	25.0	39.5	18.0	1.580	2.785	1.760	1.410	.890	.505	5	3	5	39	31
20.5	24.0	44.0	20.5	1.565	3.310	2.105	1.695	1.080	.510	5	4	5	52	44
26.0	30.0	48.5	21.5	1.415	2.510	1.765	1.210	.850	.475	5	5	5	40	23
23.7	27.5	44.5	20.5	1.470	2.672	1.802	1.355	.915	.502	5	6	5	69	53
26.3	33.0	49.0	22.3	1.580	2.563	1.606	1.283	.800	.493	6	1	5	35	11
24.2	26.5	44.0	21.0	1.337	2.492	1.857	1.310	.975	.520	6	2	5	30	27
21.0	23.0	42.0	20.0	1.410	3.000	2.110	1.580	1.110	.520	6	3	5	65	57
27.6	33.3	52.3	24.0	1.460	2.476	1.696	1.230	.840	.490	6	4	5	42	36
29.0	34.5	50.0	22.5	1.430	2.200	1.550	1.075	.750	.485	6	5	5	34	09
21.0	23.5	43.0	20.5	1.455	3.080	2.115	1.620	1.110	.520	6	6	5	52	22
20.7	21.5	53.0	26.5	1.325	4.062	3.047	2.205	1.650	.540	6	7	5	77	20
32.5	43.0	55.0	23.0	1.580	2.090	1.320	.940	.590	.440	6	8	5	28	07

TABLE 5. EMPIRICAL PLANT COMMUNITY SIGNATURE MEANS AND RATIOS EXTRACTED FROM LANDSAT DATA FOR ARIZONA TEST SITES.

Chan 4	Chan 5	Chan 6	Chan 7	$R_{5,4}$	$R_{6,4}$	$R_{6,5}$	$R_{7,4}$	$R_{7,5}$	$R_{7,6}$	Site	P.C.	Date	% Veg.	% Latr
49.100	75.000	89.100	31.800	1.682	2.186	1.291	.821	.485	.392	1	1	2	08	06
50.600	76.300	88.200	31.800	1.653	2.076	1.250	.788	.475	.392	1	2	2	08	06
50.500	78.500	86.600	32.900	1.719	2.039	1.180	.820	.475	.409	1	3	2	05	05
50.000	76.200	79.000	31.900	1.674	1.854	1.103	.801	.474	.428	1	4	2	07	02
51.200	74.700	78.300	31.000	1.582	1.782	1.121	.753	.473	.418	1	5	2	16	03
52.000	74.600	80.100	30.900	1.549	1.792	1.154	.736	.474	.416	1	6	2	14	05
49.100	77.200	83.900	32.600	1.745	2.041	1.163	.844	.482	.420	1	7	2	03	02
51.600	75.500	77.800	30.800	1.588	1.752	1.099	.742	.465	.420	1	8	2	06	03
50.800	77.300	87.700	32.000	1.671	2.057	1.215	.791	.471	.395	1	9	2	03	03
49.100	78.100	92.200	32.500	1.768	2.265	1.274	.842	.471	.388	1	10	2	03	00
50.100	77.000	79.600	31.700	1.692	1.874	1.104	.800	.468	.423	1	11	2	23	03
43.800	65.000	75.200	26.900	1.650	2.118	1.273	.806	.487	.398	1	13	2	14	05
41.700	59.800	63.900	23.400	1.594	1.882	1.177	.744	.463	.404	2	1	2	17	05
39.205	55.641	57.590	22.154	1.583	1.811	1.141	.766	.480	.419	2	2	2	16	04
33.600	47.000	51.300	19.300	1.590	2.000	1.260	.840	.523	.416	2	3	2	10	00
38.143	51.857	53.429	21.000	1.503	1.723	1.146	.754	.499	.434	2	4	2	17	06
47.000	67.500	77.700	25.900	1.571	1.989	1.263	.698	.443	.373	3	1	2	09	06
45.900	64.700	64.600	24.700	1.538	1.655	1.073	.683	.444	.410	3	3	2	12	06
45.700	68.000	69.200	26.800	1.647	1.805	1.092	.757	.457	.416	3	4	2	12	07
35.000	48.000	57.200	18.400	1.540	2.061	1.322	.744	.482	.381	3	5	2	10	06
46.600	67.300	83.000	26.400	1.583	2.177	1.362	.724	.455	.364	3	6	2	13	06
48.700	70.700	83.800	27.000	1.586	2.050	1.297	.695	.435	.362	3	7	2	06	04
47.600	68.300	79.200	26.200	1.567	2.013	1.266	.696	.443	.375	3	8	2	09	06
48.700	71.000	72.500	28.100	1.591	1.747	1.094	.726	.454	.412	3	9	2	04	03
48.500	71.000	80.500	27.600	1.600	1.991	1.234	.716	.445	.381	3	10	2	08	02
52.200	76.600	76.700	29.500	1.593	1.697	1.063	.696	.435	.407	3	11	2	04	03
53.300	79.200	79.400	31.500	1.615	1.721	1.060	.728	.446	.420	3	12	2	02	02
43.500	63.200	63.000	23.700	1.610	1.728	1.074	.706	.437	.407	3	13	2	08	05
48.500	70.800	83.900	27.800	1.598	2.079	1.293	.724	.451	.368	3	14	2	04	03

TABLE 6. EMPIRICAL SOIL SIGNATURE MEANS AND RATIOS EXTRACTED FROM LANDSAT DATA FOR ARIZONA TEST SITES.

Soil	Chan 4	Chan 5	Chan 6	Chan 7	$R_{5,4}$	$R_{6,4}$	$R_{6,5}$	$R_{7,4}$	$R_{7,5}$	$R_{7,6}$
1	52.000	74.667	76.250	30.917	1.553	1.698	1.088	.737	.471	.432
2	--	--	--	--	--	--	--	--	--	--
3	43.917	64.833	67.500	27.000	1.641	1.859	1.127	.807	.491	.430
4	41.833	60.056	61.444	23.556	1.595	1.784	1.116	.744	.463	.415
5	39.263	55.763	57.789	22.184	1.585	1.815	1.143	.765	.479	.418
6	38.143	51.857	53.429	21.000	1.503	1.723	1.146	.754	.498	.434
7	33.667	47.000	51.333	19.333	1.590	2.000	1.260	.840	.523	.417
8	33.833	45.500	47.333	17.500	1.517	1.792	1.180	.743	.490	.412
9	46.750	67.000	67.750	26.625	1.569	1.711	1.086	.727	.461	.422
10	52.250	76.625	76.750	29.500	1.594	1.697	1.064	.696	.435	.407
11	50.091	76.273	79.000	31.909	1.674	1.854	1.104	.802	.474	.428
12	50.677	76.258	79.581	32.065	1.649	1.844	1.113	.793	.479	.427
13	48.786	71,071	72.571	28.143	1.591	1.747	1.094	.726	.454	.413
14	50.100	75.700	78.850	31.950	1.660	1.852	1.110	.804	.481	.430
15	48.500	70.375	73.125	27.750	1.585	1.774	1.116	.727	.454	.405
16	50.151	76.945	79.507	32.192	1.691	1.869	1.101	.809	.476	.430
17	44.667	65.611	66.111	25.333	1.629	1.767	1.083	.732	.448	.412
18	47.000	67.667	67.833	25.944	1.576	1.698	1.073	.699	.443	.411
19	47.333	67.762	67.810	26.143	1.561	1.678	1.072	.697	.446	.413
20	51.438	76.000	75.875	29.750	1.610	1.711	1.058	.717	.441	.417
21	48.000	68.000	67.625	26.250	1.540	1.641	1.062	.689	.446	.417
22	--	--	--	--	--	--	--	--	--	--
23	--	--	--	--	--	--	--	--	--	--

soil table in Appendix B (page 210), which gives soil composition as recorded during field work.

3.4 Theoretical Approach from Field Spectra Data

Theoretical plant community spectra were also formed for comparison with actual LANDSAT data. The individual spectral reflectivities in Table 3 were mixed in the proportions in which they occurred in the plant community as determined by field procedure in Section 2.1. The resultant summation of reflectance values is assumed to be representative of the natural plant community and approximately correlative with the integrated signature collected in a LANDSAT pixel over that plant community.

New theoretical plant community spectra must be made up for each date, just as new data must be collected by LANDSAT for each date when plant community changes from date to date are to be examined. Where data for any one species had been collected, each of the experiment dates (four for Montana and one for Arizona) was used in the makeup of the theoretical spectra for that date. Where spectral measurements were not available for a particular species on one or more of the dates, substitution of the spectrum collected on the next nearest date was necessary. In some cases, where a plant spectrum was only available for one date, the same spectrum had to be used in signatures for all the dates. This did occur in a few instances, but rarely for non-evergreen plants, which made up a substantial percentage of the ground area. To the extent that spectra were used for theoretical signatures from inappropriate dates, and that those spectra were not representative of the plant for that date, theoretical studies of time-dependent recognition ability will be adversely affected. In some cases a plant species for which spectral measurement was not available constituted more than a trace amount of the vegetation in a plant community (usually only a very small percentage). In these cases, the field worker advised whether a species in question was very similar to another species for which a spectral measurement was available, or whether the contribution of that plant species to the overall community was small enough that other percentages should be prorated to make up for its absent spectrum. In summary, the theoretical spectral signatures are the best representation of those communities we could derive from the available field data. In spite of some small compromises, in general the availability of data was excellent. Differences due to use of the same spectral information for more than one date will be more significant than will those resulting from substitution of one species for another, for this was only necessary for plant types represented in small percentages. Results pertaining to comparison of dates should be evaluated with consideration of these substitutions.

Appendix C lists the spectra used in the construction of theoretical plant communities in Montana, referenced by identification numbers and dates corresponding to Table 3. The means for theoretical plant community signatures for Montana test sites for Date 5 (June 23, 1975) are given in Table 7A. The means for

TABLE 7A. THEORETICAL PLANT COMMUNITY SIGNATURE MEANS CALCULATED FROM FIELD SPECTRA FOR MONTANA TEST SITES.

$\rho(4)$	$\rho(5)$	$\rho(6)$	$\rho(7)$	$\frac{\rho(5)}{\rho(4)}$	$\frac{\rho(6)}{\rho(4)}$	$\frac{\rho(6)}{\rho(5)}$	$\frac{\rho(7)}{\rho(4)}$	$\frac{\rho(7)}{\rho(5)}$	$\frac{\rho(7)}{\rho(6)}$	Site	P.C.	Date	% Veg.	% Grass
12.982	15.203	26.769	37.635	1.171	2.062	1.761	2.899	2.475	1.406	4	1	5	52	22
26.586	34.156	39.858	45.333	1.285	1.499	1.167	1.705	1.327	1.137	4	2	5	15	02
16.248	19.190	28.771	37.570	1.181	1.771	1.499	2.312	1.958	1.306	4	3	5	46	31
18.584	21.559	33.065	40.853	1.160	1.779	1.534	2.198	1.895	1.236	4	4	5	57	19
23.621	28.138	35.175	41.230	1.191	1.489	1.250	1.745	1.465	1.172	4	5	5	32	24
20.132	24.359	31.140	36.923	1.210	1.547	1.278	1.834	1.516	1.186	4	6	5	47	38
19.378	22.796	33.403	41.863	1.176	1.724	1.465	2.160	1.836	1.253	4	7	5	53	25
28.309	37.025	42.699	50.441	1.308	1.508	1.153	1.782	1.362	1.181	4	8	5	16	12
13.268	14.641	34.962	52.116	1.103	2.635	2.388	3.928	3.560	1.491	4	9	5	70	35
17.692	21.370	29.280	31.858	1.208	1.655	1.370	1.801	1.491	1.088	5	1	5	43	21
25.351	31.122	35.959	39.567	1.228	1.418	1.155	1.561	1.271	1.100	5	2	5	16	07
22.463	26.424	33.452	36.100	1.176	1.489	1.266	1.607	1.366	1.079	5	3	5	39	31
18.108	21.215	28.965	33.561	1.172	1.600	1.365	1.853	1.582	1.159	5	4	5	52	44
18.264	22.364	28.888	31.867	1.224	1.582	1.292	1.745	1.425	1.103	5	5	5	40	23
15.740	17.875	30.116	38.849	1.136	1.913	1.685	2.468	2.173	1.290	5	6	5	69	53
18.575	22.710	30.209	36.631	1.223	1.626	1.330	1.972	1.613	1.213	6	1	5	35	11
25.447	30.319	36.487	42.101	1.191	1.434	1.203	1.654	1.389	1.154	6	2	5	30	27
16.755	19.531	29.531	37.622	1.166	1.762	1.512	2.245	1.926	1.274	6	3	5	65	57
22.562	26.098	30.610	36.231	1.157	1.357	1.173	1.606	1.388	1.184	6	4	5	42	36
19.276	22.764	29.492	34.388	1.181	1.530	1.296	1.784	1.511	1.166	6	5	5	34	09
20.612	24.005	33.053	39.731	1.165	1.604	1.377	1.928	1.655	1.202	6	6	5	52	22
14.853	16.541	28.694	37.930	1.114	1.932	1.735	2.554	2.293	1.322	6	7	5	77	20
22.949	27.755	34.218	38.590	1.209	1.491	1.233	1.682	1.390	1.128	6	8	5	28	07

TABLE 7B. THEORETICAL PLANT COMMUNITY SIGNATURE MEANS CALCULATED FROM FIELD SPECTRA FOR ARIZONA TEST SITES.

$\rho(4)$	$\rho(5)$	$\rho(6)$	$\rho(7)$	$\frac{\rho(5)}{\rho(4)}$	$\frac{\rho(6)}{\rho(4)}$	$\frac{\rho(6)}{\rho(5)}$	$\frac{\rho(7)}{\rho(4)}$	$\frac{\rho(7)}{\rho(5)}$	$\frac{\rho(7)}{\rho(6)}$	Site	P.C.	Date	% Veg.	% Latr.
19.916	21.167	24.061	28.393	1.063	1.208	1.137	1.426	1.341	1.180	1	1	2	08	06
20.024	21.300	23.930	28.048	1.064	1.195	1.123	1.401	1.317	1.172	1	2	2	08	06
19.387	28.514	32.224	37.305	1.471	1.662	1.130	1.924	1.308	1.158	1	3	2	05	05
20.227	21.457	23.995	28.060	1.061	1.186	1.118	1.387	1.308	1.169	1	4	2	07	02
18.333	26.528	30.173	35.156	1.447	1.646	1.137	1.918	1.325	1.165	1	5	2	16	03
25.164	31.472	34.886	40.837	1.251	1.386	1.109	1.623	1.298	1.171	1	6	2	14	05
19.687	28.968	32.634	37.735	1.471	1.658	1.127	1.917	1.303	1.156	1	7	2	03	02
19.174	28.083	32.331	37.933	1.465	1.686	1.151	1.978	1.351	1.173	1	8	2	06	03
20.656	21.912	24.510	28.629	1.051	1.187	1.119	1.386	1.307	1.168	1	9	2	03	03
19.682	28.921	33.164	38.829	1.469	1.685	1.147	1.973	1.343	1.171	1	10	2	03	00
17.174	24.541	31.840	40.207	1.429	1.854	1.297	2.341	1.638	1.263	1	11	2	23	03
18.234	26.380	31.913	38.704	1.447	1.750	1.210	2.123	1.467	1.213	1	12	2	15	02
18.886	24.110	26.536	29.321	1.277	1.405	1.101	1.553	1.216	1.105	1	13	2	14	05
19.198	20.438	23.134	27.260	1.065	1.205	1.132	1.420	1.334	1.178	1	14	2	16	03
16.098	21.548	25.336	30.837	1.339	1.574	1.176	1.916	1.431	1.217	2	1	2	17	05
11.371	14.848	24.532	28.216	1.306	2.157	1.652	2.481	1.900	1.150	2	2	2	16	04
10.414	13.177	15.412	18.437	1.265	1.480	1.170	1.770	1.399	1.196	2	3	2	10	00
11.046	14.429	23.860	27.245	1.306	2.160	1.654	2.466	1.888	1.142	2	4	2	17	06
20.845	28.100	33.278	44.310	1.348	1.596	1.184	2.126	1.577	1.332	3	1	2	09	06
20.344	26.244	32.353	40.515	1.290	1.590	1.233	1.991	1.544	1.252	3	2	2	25	04
13.918	17.511	20.731	24.787	1.258	1.489	1.184	1.781	1.415	1.196	3	3	2	12	06
13.788	17.384	20.399	24.095	1.261	1.479	1.173	1.748	1.386	1.181	3	4	2	12	07
15.672	20.638	23.172	25.340	1.317	1.479	1.123	1.617	1.228	1.094	3	5	2	10	05
13.849	17.438	20.618	24.576	1.259	1.489	1.182	1.775	1.409	1.192	3	6	2	13	06
20.702	23.337	34.849	43.428	1.127	1.683	1.493	2.098	1.861	1.246	3	7	2	06	04
20.798	28.057	33.158	44.030	1.349	1.594	1.182	2.117	1.569	1.328	3	8	2	09	06
14.189	17.972	20.434	23.579	1.267	1.440	1.137	1.662	1.312	1.154	3	9	2	04	03
13.943	17.648	20.391	23.961	1.266	1.462	1.155	1.719	1.358	1.175	3	10	2	08	02
20.919	23.579	35.103	43.576	1.127	1.678	1.489	2.083	1.848	1.241	3	11	2	04	03
21.136	23.821	35.357	43.724	1.127	1.673	1.484	2.059	1.836	1.237	3	12	2	02	02
13.923	17.605	20.319	23.740	1.264	1.459	1.154	1.705	1.349	1.168	3	13	2	08	05
21.514	29.089	34.085	45.256	1.352	1.584	1.172	2.104	1.556	1.328	3	14	2	04	03

theoretical plant community signatures for Arizona for Date 2 (May 20, 1975) are given in Table 7B.

3.5 Spectral Interpretation and Statistical Prediction

Both the extracted signatures and theoretical signatures of all the plant communities were used as data sets for statistical studies. Linear regressions were run to determine how well LANDSAT data, specifically MSS channel 5 and $R_{7,5}$ in Montana and MSS channel 5 and $R_{7,5}/_{5,4}$ in Arizona, correlated with vegetation cover as it was determined through fieldwork (see Section 5). In addition, multi-step tests were run to choose optimal spectral parameters by using single channel and ratio values as independent variables and a physical parameter, such as percent vegetation, as a dependent variable.

The statistical method chosen to determine the best regression equations for this investigation is a forward, stepwise linear regression (Draper and Smith, 1966). This technique is available in the University of Michigan's MIDAS[3] Statistical Laboratory software system. The forward, stepwise linear regression method seeks to find the best linear combination of independent variable (X_i) for predicting the dependent variable (Y). The following steps were used:

1. The X_i variable (for example, X_1) which is most highly correlated with Y is found and a least squares equation

[3]MICHIGAN INTERACTIVE DATA ANALYSIS SYSTEM

of the predicted value of Y is calculated, such that $Y = f(X_1)$. If an F-test indicates that the regression is significant the procedure continues.

2a. The remaining X_i variables are searched, and the one with the highest partial correlation (i.e. with the effects of X_1 removed) is added to the model. A partial F-test is performed to test if this new variable accounts for a significant part of the remaining residual sum of squares. If it does, it is included in the model. This test is conducted at a prescribed level.

2b. At this point the variables already in the model are treated as if they were the last to enter. For each one a partial F-test is performed to determine if they still account for a significant portion of the residual sum of squares. It might be the case that a variable previously included is highly correlated with the variable that entered at this step. If that is the case it might fail the F-test and be excluded from the model. These series of F-tests are also conducted at a prescribed level, not necessarily the same as the level for inclusion.

3. The procedure is continued until it is not possible to add any new variables to the model due to the fact that they cannot account for a significant portion of the remaining residual sum of squares.

An example of the forward, stepwise linear regression results is given in Table 8. There were N = 26 cases, or plant communities,

TABLE 8. EXAMPLE OF MULTIPLE LINEAR REGRESSION USED FOR GENERATION OF PREDICTIVE MODELS FOR OPTIMAL PROCESSING OF LANDSAT DATA.

A. Forward stepwise multiple regression for theoretical ratio spectral parameters with percent vegetation for Montana data, Date 5:

N = 26 cases
Significance of regression = .000
R^2 = .930
S.E. of estimate = 5.02

Step	Variable	R^2	S.E. of Estimate
1	$R_{5,4}$ in	.740	8.98
2	$R_{6,4}$ in	.799	8.09
3	$R_{6,5}$ in	.827	7.70
4	$R_{7,5}$ in	.839	7.64
5	$R_{7,6}$ in	.926	5.32
6	$R_{7,4}$ in	.931	5.29
7	$R_{6,5}$ out	.930	5.16
8	$R_{5,4}$ out	.930	5.02

B. Variables in the final regression:

Variable	Coefficient	S.E. of Coefficient
Constant	-546	76.0
$R_{6,4}$	366	49.3
$R_{7,4}$	-411	41.4
$R_{7,5}$	180	22.4
$R_{7,6}$	420	57.0

C. Variables omitted from the final regression:

Variable	Signif*
$R_{5,4}$	.907
$R_{6,4}$	.924

*Significance level for partial F-test conducted at last step.

used in this particular regression of theoretical plant community signatures with percent vegetation. Section A gives the regression step by step, showing at what step each variable was included or excluded. All possible regressions could be examined, but this would be a cumbersome procedure. An alternative, more efficient method is to use stepwise regression with less restrictive acceptance and rejection levels (Draper and Smith, 1966). The advantage of this method is that the partial correlations of the variables yet to enter the model with those already in the model are used to select the next variable to enter which will contribute most to the reduction of the standard error (S.E.). The acceptance and rejection levels can be increased until S.E. is no longer reduced. The criteria for constructing our models was to maximize the multiple coefficient of determination (R^2) and minimize S.E., while the significance remained below .05. The progressive improvement in R^2 and S.E. of the estimate with each step can also be seen. For example, in the fifth step (of a total of eight steps) $R_{7,6}$ was included and at that point the $R^2 = .92615$ and S.E. = 5.3210.

In Section B, the variables which are included in the final equation are shown with their coefficients. The linear equation determined by the regression includes an additive constant (the coefficient of "Constant" on Table 8) and the coefficient for each selected variable. For instance, the linear equation which has been determined in the example regression, herein referred to as a predictive model, is the following:

$$\% \text{ Vegetation} = 546 + (366)R_{7,4} - (411)R_{7,4} + (180)R_{7,5} + (420)R_{7,6}$$

In Section C, the variables which were not included by the regression in the final equation are given. Note that the significance of each is greater than .9, indicating they have little new information to contribute to the accuracy of the equation.

4.0 PROCESSING

4.1 Enhancement by LANDSAT MSS Channel 5

Maps of LANDSAT channel 5 were made for comparison with other processed products. We wanted to test what, if any, improvement more complete processing allowed in the mapping of vegetative types in Montana and Arizona. Levels on the maps were chosen to optimize the detail of the features recognizable from field work. It became apparent that tenlevels of single channel 5 provided more variability than was easily interpreted on a graymap output. In Montana, where high contrast was available because of higher vegetation cover, seven gray levels have been used in graymaps. In contrast only five were used in Arizona.

There could be several explanations for the variability seen. The first may be that the radiometric calibration among detectors of LANDSAT is such that the variability in the signature obscures recognizable small scale features. More likely, the integration of texture, form, color, etc. done by the field observer of these features smooths out some of the variability that actually is occurring on the ground. In fact, there is more detailed information available than we can readily interpret, at least in some of the physical features present. Contrast allowed by graymap symbols was not a factor, as we evaluated the levels individually. In addition, some differences are seen on single channel maps that are due to topography. A human observer overlooks small differences in tone due to illumination and relies on texture and form to recognize the similarities present. It was felt that a true comparison of the products would not be possible without unifying the number of levels allowed over the same variation of any one product. Therefore, all other products in Montana were made with seven comparable gray levels and those in Arizona were made with six gray levels.

4.2 Enhancement by LANDSAT Spectral Ratios

Ratioing, when the correct atmospheric and noise filtering criteria have been applied, is a relatively simple and accurate type of enhancement processing. In addition, some of the disadvantages of single channel information can be avoided by use of ratios through cancellation of environmental factors (see Section 3.2). A ratio of two channels of data registered point for point also allows quantitative comparison of spectral information. It is generally accepted in the literature that $R_{7,5}$ correlates relatively well with percent vegetation cover; specifically with percent green vegetation. Vigorous vegetation has a very low relative reflectance in the visible red (LANDSAT channel 5) and vegetation in general is very high in the infrared (LANDSAT channels 6 and 7). When these two channels are ratioed, channel 7 divided by channel 5, vigorous vegetation acquires very high $R_{7,5}$ data values, while areas with little vegetation have low values.

For Montana, $R_{7,5}$ maps were produced to optimally recognize vegetation groups known through field work. Some plant communities for which recognition was desirable varied appreciably in vegetation cover and could be expected to be recognized on any map of this parameter. Others, although differing in plant composition, were similar in percent vegetation, and for data collected at this time of year, look similar in $R_{7,5}$. In Arizona, however, vegetation cover--particularly green vegetation--was so sparse, that it was evident that features recognized were not really correlated with vegetation. Instead of using only the physical information available in an $R_{7,5}$ ratio, we combined that with information available on color supplied in a ratio of red to green, or channel 5 divided by channel 4. In an $R_{5,4}$, red things attain high values, white things medium values, and green things very low values. Dividing $R_{7,5}$ by $R_{5,4}$, one would expect vigorous plant material, which is high in the numerator and low in the denominator to become even more separated to the high end of the values. $R_{7,5}/R_{5,4}$ should maximize the influence of vegetation. While $R_{7,5}$ is the highest for high vegetation cover, it can also be high for common iron oxides. However, $R_{5,4}$ will always be at a minimum for things that appear green and high for red ferric iron oxides. This ratio of ratios allows the range for green plants in soils ranging from red to white to expand slightly from that available in a single ratio.

4.3 Enhancement by Theoretical Predictive Models

LANDSAT data values must be normalized before they are compared with the theoretical data. Assuming that the additive factor, L_λ (path from Equation 1 of Section 3.2, has been eliminated for each channel through dark object subtraction, normalization of ratios is accomplished by multiplying the $R_{i,j}$ ratio derived from LANDSAT data (see Equation 3) by a normalization coefficent.

The normalization coefficent, $K_{i,j}$, is defined by the slope of a line defined by correlation of theoretical ratios for plant communities with their comparable LANDSAT ratio values. There are several methods for finding the slope of the line, but all are dependent on having one, or preferably more, theoretical plant community spectra that are known to be representative of an area in the scene from which LANDSAT data can be extracted. Assuming dark object subtraction takes into account accurately the additive values in the scene, zero and one other point will define the slope of a line, giving the normalization coefficient, $K_{i,j}$:

$$K_{i,j} = \frac{\rho(i)/\rho(j)}{R_{i,j}} \tag{5}$$

where $R_{i,j}$ is the ratio of the ith and jth LANDSAT MSS Channels and $\rho(i)/\rho(j)$ is the reflectance ratio calculated from the theoretical spectrum of that plant community. Where only one data point is used, the coefficient for that plant community becomes the normalization coefficient to be used to correct all data points. Clearly, the accuracy with which that one point is known is extremely important.

Obviously, the accuracy of $K_{i,j}$ improves as the number of accurately known plant community values increases. Assuming that dark object subtraction had corrected for the additive term, we ran a linear regression forced through the origin on 18 points for each spectral ratio (see Figure 9), where each dot on the graph represents one plant community. Such a procedure is most accurate if the values available span the full range of $R_{i,j}$. The normalization coefficients determined by this procedure are given in Table 9, and have been applied to Equation 6 below.

To generate an optimal prediction model, the results of the regression analysis gives a formula representing a non-unique solution for estimating the dependent variable. Any model used in Montana derived from theoretical values (values based on field spectra) would have to be scaled using these normalization coefficients before it could be applied to actual LANDSAT data. Remembering that $\rho(i)/\rho(j) = K_{i,j} R_{i,j}$, the formula for each model is similar to the following:

$$F = A_o + (0.80582)A_{5,4}R_{5,4} + (0.56655)A_{6,4}R_{6,4} + (0.69788)A_{6,5}R_{6,5} + (1.3294)A_{7,4}R_{7,4} + (1.6392)A_{7,5}R_{7,5} + (2.3851)A_{7,6}R_{7,6} \quad (6)$$

where the A_o and $A_{i,j}$ are calculated by the regression analysis of $\rho(i)/\rho(j)$ versus F, $R_{i,j}$ are the spectral ratios calculated from LANDSAT data, and F is the function being mapped (such as percent vegetation cover) with LANDSAT data.

Before gathering the theoretical predictive model for percent vegetation, some tests for optimal combinations of spectral parameters were run, per the description of statistical procedures in Section 3.5. The significance level of the F-statistic was confined to less than or equal to .05 for all valid models; the standard error was minimized within that significance level. Three

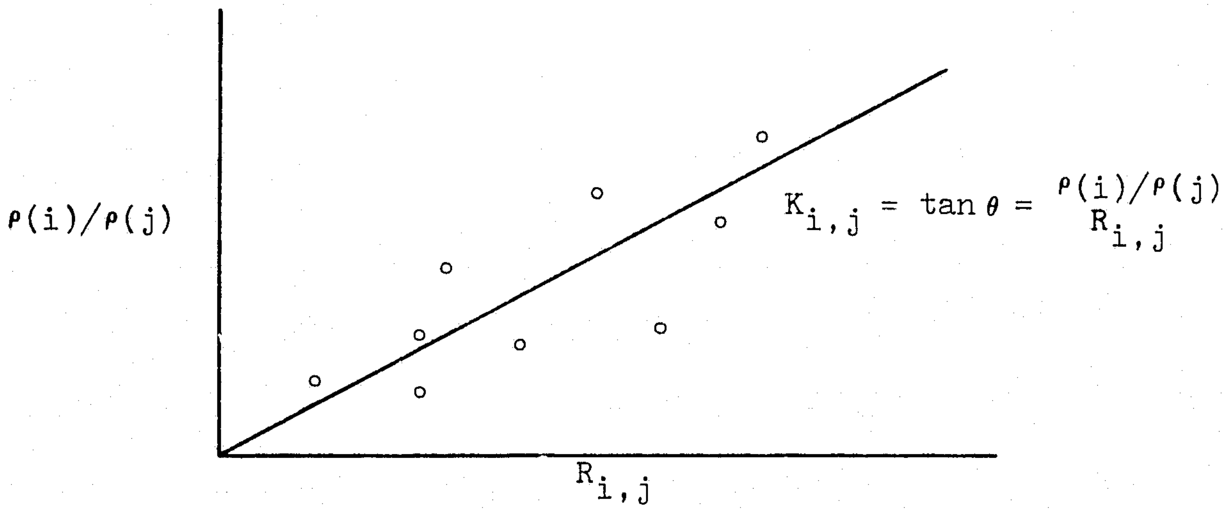


FIGURE 9. HYPOTHETICAL EXAMPLE OF NORMALIZATION COEFFICIENT REGRESSION.

$R_{i,j}$	$K_{i,j}$
$R_{5,4}$	.80582
$R_{6,4}$	.56655
$R_{6,5}$	.69788
$R_{7,4}$	1.3294
$R_{7,5}$	1.6392
$R_{7,6}$	2.3851

TABLE 9. NORMALIZATION COEFFICIENTS ($K_{i,j}$) FOR THEORETICAL DATA OF MONTANA TEST SITE 4, JUNE 23, 1975.

data sets were used: single channel values alone, ratio values alone, and all ten spectral values together. Each was run for the separate dates to find the best combinations for each date. Table 10 shows the optimal solutions and the accompanying statistics for each solution. Spectral parameters in the "Priority of Parameters" column are listed in the order of selection, first to last. As can be seen from Table 10, there is a different model for each date and each different set of input parameters (single channels, ratios, and combinations of single channels and ratios).

The resultant model actually applied to the data to generate the product included in this study was that using only ratio inputs for Date 5 (the seventh model in Table 10, where R^2 = .93138). This model utilizes four ratios and the solution to the function was as follows:

$$\% \text{ VEGETATION (Theoretical)} = (-546.25) + (0.56655)(365.55)R_{6,4} + (1.3294)(-411.36)R_{7,4} + (1.6392)(180.26)R_{7,5} + (2.381)(420.08)R_{7,6} \quad (7)$$

where the A_o and $A_{i,j}$ as determined from regression analysis were A_o = -546.25; $A_{6,4}$ = 365.55; $A_{7,4}$ = -411.36; $A_{7,5}$ = 180.26; $A_{7,6}$ = 420.08; and the $K_{i,j}$ are taken from Table 10.

The application of the theoretical percent vegetation model to the June 23 data to all three Montana test sites were successful qualitatively, but not quantitatively. Whereas the % VEGETATION parameter (Theoretical) increases with increasing vegetation cover, the absolute numbers it predicted were too large. Percent vegetation should have been bounded by 0 to 100, but approximately 20 percent of the pixels in each test had values greater than 100,

TABLE 10. FORWARD REGRESSION RESULTS FOR PERCENT VEGETATION THEORETICAL MODELS IN MONTANA.

Date		Input Parameters	Level	Signif	R^2	SE	Priority of Parameters
May	17	Single	.2,.25	.0000	.813	8.016	$\rho(5)$ $\rho(4)$ $\rho(7)$
June	4	Single	.5,.6	.0000	.808	8.119	$\rho(5)$ $\rho(6)$ $\rho(4)$
June	23	Single	.1,.15	.0000	.843	7.349	$\rho(5)$ $\rho(6)$ $\rho(4)$
August	1	Single	.1,.15	.0000	.889	5.876	$\rho(5)$ $\rho(7)$ $\rho(4)$
May	17	Ratio	.75,.8	.0000	.832	8.267	$\rho(6)/\rho(5)$ $\rho(5)/\rho(4)$ $\rho(6)/\rho(4)$ $\rho(7)/\rho(4)$ $\rho(7)/\rho(6)$ $\rho(7)/\rho(5)$
June	4	Ratio	.6,.65	.0000	.859	7.572	$\rho(5)/\rho(4)$ $\rho(6)/\rho(4)$ $\rho(6)/\rho(5)$ $\rho(7)/\rho(5)$ $\rho(7)/\rho(6)$ $\rho(5)/\rho(4)$ out $\rho(7)/\rho(4)$ $\rho(5)/\rho(4)$ in
June	23	Ratio	.5,.6	.0000	.931	5.021	$\rho(5)/\rho(4)$ $\rho(6)/\rho(4)$ $\rho(6)/\rho(5)$ $\rho(7)/\rho(6)$ $\rho(7)/\rho(4)$ $\rho(6)/\rho(5)$ out $\rho(5)/\rho(4)$ out
August	1	Ratio	.7,.75	.0000	.922	5.322	$\rho(7)/\rho(5)$ $\rho(5)/\rho(4)$ $\rho(7)/\rho(4)$ $\rho(6)/\rho(4)$ $\rho(6)/\rho(5)$ $\rho(7)/\rho(6)$
May	17	Combination	.75,.8	.0000	.876	7.587	$\rho(5)$ $\rho(5)/\rho(4)$ $\rho(7)$ $\rho(7)/\rho(4)$ $\rho(4)$ $\rho(7)/\rho(5)$ $\rho(6)$ $\rho(7)/\rho(6)$

TABLE 10. CONCLUDED

Date	Input Parameters	Level	Signif	R^2	SE	Priority of Parameters	
June 4	Combination	.65,.7	.0000	.880	6.998	$\rho(5)$	
						$\rho(5)/\rho(4)$	
						$\rho(6)$	
						$\rho(7)/\rho(5)$	
						$\rho(4)$	
						$\rho(7)$	
						$\rho(6)/\rho(5)$	
						$\rho(4)$	out
						$\rho(7)/\rho(6)$	
						$\rho(7)/\rho(4)$	
						$\rho(5)$	out
						$\rho(7)/\rho(5)$	out
June 23	Combination	.5,.6	.0000	.942	5.211	$\rho(5)$	
						$\rho(5)/\rho(4)$	
						$\rho(4)$	
						$\rho(7)/\rho(5)$	
						$\rho(7)$	
						$\rho(7)/\rho(4)$	
						$\rho(6)/\rho(4)$	
						$\rho(7)/\rho(5)$	out
						$\rho(6)$	
						$\rho(7)/\rho(6)$	
August 1	Combination	.5,.6	.0000	.929	4.940	$\rho(5)$	
						$\rho(7)$	
						$\rho(7)/\rho(4)$	
						$\rho(6)$	
						$\rho(7)/\rho(6)$	
						$\rho(7)$	out
						$\rho(6)/\rho(4)$	

Single = Single channel inputs (four)
Ratio = Ratio inputs (six)
Combination = Single channel (four) and ratio (six) inputs
Level = Level of significance
Signif = Significance
R^2 = Multiple coefficient of determination
SE = Standard Error

obviously in error. There are several possible causes of the quantitative inaccuracy, but the most likely sources of error are the normalization constants ($K_{i,j}$). Had one or more large, homogeneous reference areas been selected prior to the field trips for spectral measurements, it is likely that the $K_{i,j}$ would have been more accurate. Further research is needed to find the source of quantitative error before a definitive answer can be found for the theoretical approach. It is encouraging, however, that this method was capable of qualitatively mapping vegetation cover from theoretical data. Since ratio normalization can be done with little field information when only a few points are known extremely well, the theoretical procedures could be a tremendous cost savings when perfected.

4.4 Enhancement by Empirical Predictive Models

Predictive models were tested in a manner similar to that using field spectra for target signatures extracted from the LANDSAT data. As in the automatic recognition mode and any similar supervised training procedure, the accuracy is highly dependent on location of pixels. Comparative regressions to find the optimal solution for all three spectral combinations resulted in the selection of a general function using only ratios for the June 23rd data. The statistics of the studies are presented in Table 11. The general function used was:

TABLE 11. FORWARD REGRESSION RESULTS FOR PERCENT VEGETATION AND PERCENT GRASS EXTRACTED MODELS IN MONTANA, DATE 5 (JUNE 23, 1975).

Variables	Input Parameters	Level	Signif	R^2	SE	Priority of Parameters
Total % vegetation	Single	.5,.6	.0012	.558	12.308	Chan 5 Chan 7 Chan 6
Total % vegetation	Ratio	.5,.6	.0029	.573	12.440	$R_{7,6}$ $R_{5,4}$ $R_{6,4}$ $R_{7,4}$
Total % vegetation	Combination	.7,.75	.0035	.617	12.122	Chan 5 $R_{7,6}$ $R_{5,4}$ $R_{7,4}$ Chan 7 $R_{6,4}$ $R_{7,4}$ out
Total % grass	Single	.6,.7	.0137	.422	11.747	Chan 4 Chan 6 Chan 7
Total % grass	Ratio	.45,.55	.0249	.381	12.148	$R_{7,6}$ $R_{7,5}$ $R_{6,5}$
Total % grass	Combination	.7,.75	.0037	.429	11.375	$R_{7,6}$ Chan 7

Single = Single channel inputs (four)
Ratio = Ratio inputs (six)
Combination = Single channel (four) and ratio (six) inputs
Level = Level of significance
Signif = Significance
R^2 = Multiple coefficient of determination
SE = Standard Error

$$\% \text{ VEGETATION(Extracted)} = (-7.4921) + (-119.24)R_{5,4} + (46.460)R_{6,4} + (-106.98)R_{7,5} + (401.06)R_{7,6} \quad (8)$$

where A_o and $A_{i,j}$, the coefficients, were determined from regression: $A_o = -7.4921$, $A_{5,4} = -119.24$, $A_{6,4} = 46.460$, $A_{7,5} = 106.98$, $A_{7,6} = 401.06$. Normalization constants are, of course, unnecessary. The values of data ranged from 0 to 98, values ranging within the region expected. The statistics of the extracted model show that, based on the training sets and field information prescribed, results were improved using this method over single channel or single ratio methods. These encouraging results are discussed in Section 5.0.

4.5 Automatic Recognition by Ratio Gating Logic

Initially, pixels were chosen and extracted for each of the transects for each of the three sites in Montana. This resulted in a very small sample for each target. When these targets were then tested for uniqueness, it was found that 10 of the 23 could be separated from one another. Those which were not unique from others-- the remaining 13--overlapped these 10 in many and untested ways. The result was that when automatic recognition would have assigned a 1 to a pixel, you could have said that pixel was definitely not the other 9 targets in the recognition scheme, but you could say nothing about the likelihood that it was any of the other 13.

One of the problems incurred in this procedure was that many targets were similar. It would have been possible to reevaluate those targets, grouping them into acceptable groups and testing for their uniqueness again. However, this was not done formally, as it was determined that there were some groups which would have still been impossible to separate. Accuracy was difficult to determine, for no measure of variability within plant communities was given in the field data. Until it is known what physical parameters are the most significant spectrally, it is difficult to choose a procedure.

Additional automatic recognition possibilities were explored only for Site 4, the Liscom Creek site. We had found, for example, that upland grasslands and pine-bunchgrass of this area were difficult to separate. Recognizing that information taken from an aerial photograph may not be strictly correlative with the ground data we had been working with up to that point, we nevertheless selected new and more training pixels for each of eight plant communities in the Liscom Creek site (barren hills and the coal mine rehabilitation area were combined into one plant community). These were treated identically to the pixels chosen previously, the average and range noted for each plant community. Whether or not these adhere strictly to the descriptions as previously defined, it was agreed that these were representative of areas worthy of separation. The resulting ranges were as shown in Table 12A. As can be seen when comparing single channels and ratios, no combination will allow completely unique distinction of even the eight plant communities in Site 4. Some which are physically very distinctive and important from a management

TABLE 12A. EMPIRICAL PLANT COMMUNITY SIGNATURE RANGES CALCULATED FROM LANDSAT DATA FOR AUTOMATIC RECOGNITION BY RATIO GATING LOGIC FROM MONTANA SITE 4, DATE 5.

P.C.	Chan 4	Chan 5	Chan 6	Chan 7	P.C. Name
1	12-16	15-23	37-48	18-25	Silver Sage - Grass Flat
2,8	15-23	25-36	39-50	19-23	Barren Hillside
3	10-15	15-18	37-52	18-28	Upland Grass
4	9-10	14-16	30-44	15-22	Pine - Bunchgrass
5	14-16	20-23	35-39	17-21	Ridgetop
6	11-15	18-19	37-42	18-21	Bluestem Hillside
7	10-14	13-19	39-53	20-27	Dandelion - Grass Bottom
9	9-10	8-12	51-66	28-37	Alfalfa

P.C.	$R_{5,4}$	$R_{6,4}$	$R_{6,5}$	$R_{7,4}$	$R_{7,5}$	$R_{7,6}$	P.C. Name
1	107-153	264-369	205-270	128-178	94-147	46-54	Silver Sage - Grass Flat
2,8	131-200	205-306	136-176	91-146	62-84	44-48	Barren Hillside
3	120-150	273-430	211-325	133-230	111-175	48-56	Upland Grass
4	140-166	370-440	214-275	166-220	107-142	45-52	Pine - Bunchgrass
5	142-153	243-260	169-177	121-140	82-95	48-53	Ridgetop
6	126-172	273-336	194-233	138-172	94-111	47-51	Bluestem Hillside
7	125-163	325-480	243-369	175-270	125-207	48-56	Dandelion - Grass Bottom
9	88-133	510-688	425-762	280-411	233-462	54-62	Alfalfa

TABLE 12B. EMPIRICAL PLANT COMMUNITY SIGNATURE RANGES FROM LANDSAT DATA ACTUALLY USED FOR AUTOMATIC RECOGNITION MAP FOR MONTANA SITE 4, DATE 5.

Order of Use	P.C.	$R_{5,4}$	$R_{6,4}$	$R_{6,5}$	$R_{7,4}$	$R_{7,5}$	P.C. Name
1	5	141-153	242-261	168-183	120-141	081-095	Ridgetop
2	9	001-135	409-800	408-800	269-800	222-800	Alfalfa
3	2	128-800	001-311	001-178	001-149	001-085	Barren Hillside
4	3	119-146	265-438	199-332	128-235	102-179	Upland Grass
5	6	124-175	270-339	183-217	137-174	093-112	Bluestem Hillside
6	1	104-155	260-363	202-274	126-179	092-150	Silver Sage - Grass Flat
7	4	145-167	331-445	211-281	164-225	105-144	Pine - Bunchgrass
8	7	123-165	314-800	234-800	172-800	120-800	Dandelion - Grass Bottom

P.C. = Plant Community

point of view simply could not be separated.

Uniqueness of a target can be considered in terms of the separation of signature means or lack of overlap in the range. Ratio gating logic in which an equal probability is assigned across the range, depends on lack of overlap from one target to another. Without probability decisions to select the most likely class recognition for a pixel which fits more than one category, recognition procedures require a bi-level decision process. Target-order dependency produced the need for a step in the decision process to choose the logical order for the targets. The first step in ordering targets was to choose narrow targets which nested in a broad target to be recognized first. This decision was actually quite effective. Plant communities with little variation within each plant community were likely to be small, localized areas, such as ridgetops. The broader, more widely varying target enveloping such a target was likely to be more extensive and would fill in with the "other" pixels. Had the two been reversed, none of the narrow target would have been recognized.

The problem of how best to deal with overlapping and, just as importantly, noncontiguous target signatures must be dealt with according to the requirements of the study. The consequences of one method over another can be used to advantage. Some possibilities are these:

1. The ranges of the targets, if mean separation allows, can be cut back so that each target becomes unique. Now only those points fitting criteria uniquely will be recognized

and the proportion of the area mapped is very small.

2. Leave variability wide for individual plant communities allowing non-unique targets. This means the same ambiguous points which would be assigned to one or another plant community with techniques applying unequal probabilities will be recognized exclusively as the first target they fit. The ambiguity of the signature of those pixels is no longer recognized, and the earliest targets are favored. The decision to favor one class over another now highly alters the end result.
3. The area of overlap can be split, either evenly or by some rule of probability so that more points will be recognized and will be assigned to the classes they most nearly resemble. Recognition by this method will still be more sparse than the unaltered range mode because of the fewer spectral combinations allowed. Again, the natural variation of any one plant community is very important in any scheme of recognition. For example, a plant community with a wide variety of species of low green shrubs may vary less in all the LANDSAT channels than an uplands grasslands with one grass species in highly variable degrees of greening, or two spectrally dissimilar species communities with widely different proportions of the two species. Without adequate knowledge of the resulting spectral characteristics, target ranges cannot be set that are expected to include the whole area

of highly variable plant communities.

The third method of treating targets described above was originally applied to eight plant community signatures in Site 4 (Liscom Creek), Date 5 in Montana. In addition to some narrow targets being nested with broad plant communities, some targets with small partial overlap were altered to be exclusive. Otherwise, the signature range remained the same and the most populous target (according to field information) was placed first. A pixel will be recognized by the first target it satisfies in a series of targets. A target early in the decision string may artifically show more recognition than a later one. The first application of ratio gating logic resulted in reasonably accurate classification, but only 65 percent of the scene was classified.

At this point, a trade off was made in the overall objectives of the mapping project. Which is more helpful to an operational application for the BLM: mapping a portion of the scene and classifying those areas which are uniquely like the arbitrary signature you have prescribed correctly, or including areas in your classification which are similar but not like your target in order to class, or map, as much of the area as possible? Although the first procedure we used resulted in reasonable recognition, it was probably not optimal. More information on expected variability within one plant community would perhaps have allowed other decisions about target alteration.

The target ranges were then expanded symmetrically by 10 percent of the range of the target. Total recognition rose to

71.3 percent recognition. More importantly, all eight targets in the decision string increased recognition.

When the ranges were then increased another 10 percent increment (10 percent of the original target range), the first four targets gained recognition and the last four lost recognition. This was interpreted as undesirable interference of the first four targets with the second four and was rejected as a viable method for increasing meaningful recognition. One additional step was taken, however. In all five ratios, one target was clearly the highest or the lowest in value of that ratio. It was assumed that points above the maximum of the highest target were most likely to belong to that target. Points below the lowest target were assumed most likely to belong to that target. These end-member targets were then opened up to include extreme values in all the ratios. This procedure raised total recognition only less than 1 percent. The final recognition map had 72 percent total area recognized for eight plant communities (see Section 7.2). The final signature ranges used are given in Table 12B.

4.6 Automatic Recognition by Maximum Likelihood Classification

Maximum likelihood classification as compared on the Bendix Multispectral-Data Analysis System (M-DAS) was applied to one test site in each of Arizona and Montana for independent reasons. LANDSAT data signatures for the plant communities in Arizona had overlapped so much that binary sequential logic, (which has no ability to assign partial probabilities) was useless. On the other hand, single channel graymaps contained recognizable detail. This was an extreme test of the separation capabilities of maximum likelihood classification.

Conversely, in Montana, when signatures were kept narrow in binary sequential logic, adequate separation was available for recognizable classes in single channel and ratio space. However, recognition was very sparse, and although some increased recognition was allowed by increasing the width of spectral gates, the limit of this technique was reached before adequate coverage of the site could be attained. Accuracy was also asymmetrically reduced, as some targets were recognized more and some less. Maximum likelihood was perceived to be a reasonable method of allowing increased spatial coverage of the scene, while treating each target equally.

Categorical analysis was performed on three of four LANDSAT channels of data for Site 1 in Arizona. Channel 6 was too strongly banded to be used. At first, signatures were entered for all 13 plant communities in the site. A confusion matrix of the resulting classification of pixels showed that signatures for some targets were nearly identical. The number of targets was finally dropped to ten, with the assumption that some of the plant communities quite reasonably could be considered to be mixtures of two or more communities already represented.

All four single channels of data were used in categorical analysis of Site 4 in Montana. In this case the original eight plant communities were maintained, with the addition of a second, upland silver sage-grass bottom community. Where this community occurred on well drained soils in the Liscom Creek valley, its signature was quite different from those in poorly drained lowlands. The two silver sage-grass bottom communities have been shown in two shades of green in the recognition map.

Treatment of the silver sage-grass bottom community illustrates an important additional restriction we applied to our work that is not universally used. No final recognition class was represented in the classification scheme by more than one signature. In some cases the use of more than one target for a single class was necessary; this allowed collection of more pixels over several areas representing a single plant community. However, all of the pixels from multiple targets were then handled together rather than separately. The practice of using multiple signatures when a target is known to have high variability, such as using separate signatures for new, mature, and tassled corn when only the classification "corn" is desired, is a powerful spectral tool. However, we did not have ground data which allowed us to specify differences which would allow definition of two legitimate targets over one, highly variable target. It was felt that one target could more accurately represent one highly variable community; the use of multiple targets can mislead a reader into believing that the combination of high percent recognition and accuracy achieved here could be accomplished with only nine targets when it actually would have required more.

Since the purpose of this classification was to systematically increase overall recognition, no cut-off distance (in standard deviations from target means) was specified for the categorical analysis. With Site 4, 99.3 percent of the area was recognized. An evaluation of the resulting qualitative accuracy can be found in Section 6.3.

4.7 Unused Statistical Models

Other statistical models were run, but did not lead to actual processing. Table 13 shows the results of multiple linear regressions run on theoretical data at four times of year in Montana for determining percent grass cover. Similar results for an empirical model from data collected on June 23, 1975 were shown in Table 10. Unlike the percent vegetation statistics, which showed theoretical models producing higher accuracies than extractive models, extracted models more accurately predicted grass cover. Completely different ratios were used in different models, illustrating the fact that these are not unique solutions. Interestingly enough, the improved theoretical results attained for signatures developed to represent August 1 are more similar to those of the extracted data for June 23. Clearly, grass has phenological characteristics which will play an important role in recognition when the right temporal and spectral data is available.

These results are merely a start at comparing the relative merits of spectral data collected at different times. There are many additional problems to overcome when considering the actual

TABLE 13. FORWARD REGRESSION RESULTS FOR PERCENT GRASS THEORETICAL MODELS IN MONTANA.

Date		Input Parameters	Level	Signif	R^2	SE	Priority of Parameters
May	17	Single	.3,.35	.0218	.353	12.100	$\rho(6)$ $\rho(4)$
June	4	Single	.3,.4	.0230	.223	12.952	$\rho(5)$
June	23	Single	.5,.6	.0223	.316	12.449	$\rho(5)$ $\rho(4)$
August	1	Single	.6,.65	.0316	.210	12.493	$\rho(5)$ $\rho(4)$
May	17	Ratio	.5,.6	.0336	.198	13.161	$\rho(5)/\rho(4)$
June	4	Ratio	.3,.4	.0326	.200	13.144	$\rho(5)/\rho(4)$
June	23	Ratio	.5,.6	.0058	.310	12.206	$\rho(5)/\rho(4)$
August	1	Ratio	.5,.6	.0262	.410	11.780	$\rho(5)/\rho(4)$ $\rho(7)/\rho(4)$ $\rho(7)/\rho(5)$ $\rho(6)/\rho(5)$
May	17	Combination	.6.,7	.0335	.482	11.749	$\rho(6)$ $\rho(6)/\rho(4)$ $\rho(7)$ $\rho(7)/\rho(4)$ $\rho(4)$ $\rho(7)/\rho(6)$ $\rho(7)$ out
June	4	Combination	.3,.4	.0230	.223	12.952	$\rho(5)$
June	23	Combination	.7,.75	.0196	.325	12.367	$\rho(5)/\rho(4)$ $\rho(6)$
August	1	Combination	.4,.45	.0094	259	12.305	$\rho(5)$

Single = Single channel inputs (four)
Ratio = Ratio inputs (six)
Combination = Single channel (four) and ratio (six) inputs
Level = Level of significance
Signif = Significance
R^2 = Multiple coefficient of determination
SE = Standard Error

application of multitemporal information to a spectral recognition problem,not the least of which is registration of data. However, a temporal look at field spectra can help direct future efforts in optimal processing of LANDSAT data for operational applications. A forward linear regression including all spectral parameters, four single channels and six ratio values, for all four dates of theoretical data available from Montana showed that data from dates 5 and 6 (July 23, 1975 and August 1, 1975) could be combined effectively to estimate percent vegetation. Table 14 shows the results of the regression with the improvements in R^2 and the S.E. of the estimate as each spectral parameter was included. These results are promising, as the registration of LANDSAT data for two dates is probably feasible for improving recognition capabilities.

Combining data from several dates is probably less likely to be applicable, particularly from data quality considerations. Table 15, presenting the partial results of a linear regression analysis of theoretical data for predicting percent grass, shows a combination of temporal parameters that would be hard to implement on an experimental basis, let alone an operational system. These results may not actually be as promising as possible; previously described non-optimal sampling techniques (see Section 2.1) in the estimation of the grass percentages could contribute to degradation of the model.

Many combinations of spectral and temporal parameters can be evaluated with the systems we used here. In addition to multiple linear regressions, linear discriminants and other decision schemes

TABLE 14. MULTIPLE LINEAR REGRESSION FOR PERCENT VEGETATION IN MONTANA USING ALL SPECTRAL PARAMETERS.

A. Forward stepwise multiple regression:

N = 23 out of 26 cases
Significance of regression = .0000
R^2 = .94167
S.E. of estimate = 4.8747

Step	Variable		R^2	S.E. of Estimate
1	Chan 5 - Date 5	in	.77184	8.4151
2	Chan 7 - Date 6	in	.84648	7.0733
3	Chan 4 - Date 5	in	.89860	5.8977
4	Chan 4 - Date 6	in	.91380	5.6103
5	$R_{7,6}$ - Date 5	in	.93275	5.0776
6	$R_{5,4}$ - Date 5	in	.93683	5.0727
7	Chan 5 - Date 5	out	.93677	4.9236
8	Chan 5 - Date 6	in	.94167	4.8747

B. Variables in final regression:

Variable	Coefficient	S.E. of Coefficient
Constant	499.19	153.16
Chan 4 - Date 5	-1.3614	.86161
$R_{5,4}$ - Date 5	-305.18	119.39
$R_{7,6}$ - Date 5	-65.848	21.715
Chan 4 - Date 6	-10.404	6.3136
Chan 5 - Date 6	6.3793	5.5057
Chan 7 - Date 6	1.7337	.45489

C. Variables omitted from the final regression:

not included here due to length of list

TABLE 15. MULTIPLE LINEAR REGRESSION RESULTS FOR PERCENT GRASS IN MONTANA USING ALL SPECTRAL PARAMETERS.

A. Forward stepwise multiple regression:

N	= 23 out of 26 cases
Significance of regression	= .0000
R^2	= .88662
S.E. of estimate	= 6.0589

Step	Variable	R^2	S.E. of Estimate
1	$R_{5,4}$ - Date 5 in	.30983	12.206
2	$R_{5,4}$ - Date 3 in	.53411	10.276
3	$R_{5,4}$ - Date 6 in	.57608	10.057
4	$R_{6,4}$ - Date 3 in	.61164	9.8894
5	$R_{6,5}$ - Date 6 in	.77350	7.7715
6	Chan 6 - Date 4 in	.79887	7.5487
7	Chan 5 - Date 6 in	.84848	6.7669
8	Chan 4 - Date 6 in	.88662	6.0589

B. Variables in the final regression:

Variable	Coefficient	S.E. of Coefficient
Constant	1227.9	548.74
$R_{5,4}$ - Date 3	850.62	159.37
$R_{6,4}$ - Date 3	-97.326	18.010
Chan 6 - Date 4	-2.2407	.68689
$R_{5,4}$ - Date 5	-1367.3	189.82
Chan 4 - Date 6	-47.148	21.724
Chan 5 - Date 6	39.318	17.168
$R_{5,4}$ - Date 6	-370.83	403.34
$R_{6,4}$ - Date 6	50.954	28.608

C. Variables omitted from the final regression:

Variable	Signif*	Variable	Signif*
Chan 4 - Date 3	.9511	$R_{7,6}$ - Date 4	.9259
Chan 5 - Date 3	.9617	Chan 4 - Date 5	.5193
Chan 6 - Date 3	.8221	Chan 5 - Date 5	.5208

TABLE 15. CONCLUDED

Variable	Signif*	Variable	Signif*
Chan 7 - Date 3	.4426	Chan 6 - Date 5	.6894
$R_{6,5}$ - Date 3	.3739	Chan 7 - Date 5	.7524
$R_{7,4}$ - Date 3	.9326	$R_{6,4}$ - Date 5	.7631
$R_{7,5}$ - Date 3	.9803	$R_{6,5}$ - Date 5	.7723
$R_{7,6}$ - Date 3	.8078	$R_{7,4}$ - Date 5	.7785
Chan 4 - Date 4	.8015	$R_{7,5}$ - Date 5	.8008
Chan 5 - Date 4	.6989	$R_{7,6}$ - Date 5	.6558
Chan 7 - Date 4	.9933	Chan 6 - Date 6	.9920
$R_{5,4}$ - Date 4	.6463	Chan 7 - Date 6	.9614
$R_{6,4}$ - Date 4	.9832	$R_{6,4}$ - Date 6	.5097
$R_{6,5}$ - Date 4	.9473	$R_{7,4}$ - Date 6	.9653
$R_{7,4}$ - Date 4	.8355	$R_{7,5}$ - Date 6	.9313
$R_{7,5}$ - Date 4	.8346	$R_{7,6}$ - Date 6	.9816

*Significance level for partial F-test conducted at last step.

could also be evaluated using standard statistical computer programs available on multiple-use computers.

5.0 RESULTS

5.1 Enhancement Processing of Ephemeral Rangeland in Arizona

Site maps with plant communities and soil designations defined during field work are presented in Figures 10-12, for Arizona test sites. Plant communities ranged in vegetation cover estimates from 2 to 25 percent. Soil types, indicated by letters on the site maps, can be keyed to Appendix B (page 210). A comparison of plant community boundaries drawn from field data for the three sites in Arizona with graymaps of LANDSAT data showed that perennial desert vegetation is very difficult to classify using LANDSAT data. The open growth characteristics of desert trees and shrubs and the low percentage of ground covered by live plant material create a diffuse target influenced by the large percentage of background soil or rock. During frequent periods of drought such as experienced during the 1975 spring growing season, leaves are either very small and few in number or gray-green in color rather than bright green. Leaves are also covered with a thick waxy cutin as they mature. This tends to increase absorption of light in the green band and reduce reflection of infrared energy from active chlorophyll-producing cells.

Difficulties in recognizing the expected influence of vegetation in arid regions of sparse cover have precedence in the literature. In his reply to Jackson and Idso (1975), Otteman reports an "observed low reflectance in the MSS-7 (multispectral scanner) infrared band, 0.8 to 1.1 microns, of the area with an appreciable vegetation cover (Jackson and Idso, 1975) in the Western Negev was totally unexpected, and indeed referred to as the Negev infrared reflectance paradox." The apparent explanation for the anomalous reflectance of the area as deduced by Otteman was that even with 25 percent to 35 percent of the ground surface covered with vegetation; it was the intertices between the clumps of vegetation that effectively controlled the reflectances. In the Negev the intertices showed dark-gray plant litter and stablized soil. The article contrasted this reflectance with the higher values of the adjoining Sinai, where unstablized soil with a high albedo was well exposed under a mere 10 percent vegetation cover. This observation would seem to be in agreement with the findings of Baldridge, et al. (1975) in the widely differing environment of the state of Ohio. In the scheme of land use inventory categories designated for the mapping of land use in Ohio, the most dense industrial and commercial areas classed as "urban" were grouped into a vegetation cover class of 0 to 35 percent vegetation cover.

Spectral ratio $R_{7,5}$ divided by $R_{5,4}$ was used to attempt to enhance green vegetation. Areas of high percent plant cover should appear bright in this spectral combination (see Figure 13). The resulting map of $R_{7,5}/R_{5,4}$ is complex when compared to the fairly broad plant communities mapped in the field. It definitely reduced the contrast within the scene so that topographic and soil features which could be identified on those products were not recognizable here. Whether it was actually more correct for vegetation cover than the other products is questionable. Table 16 presents the results of linear regressions run for the theoretical

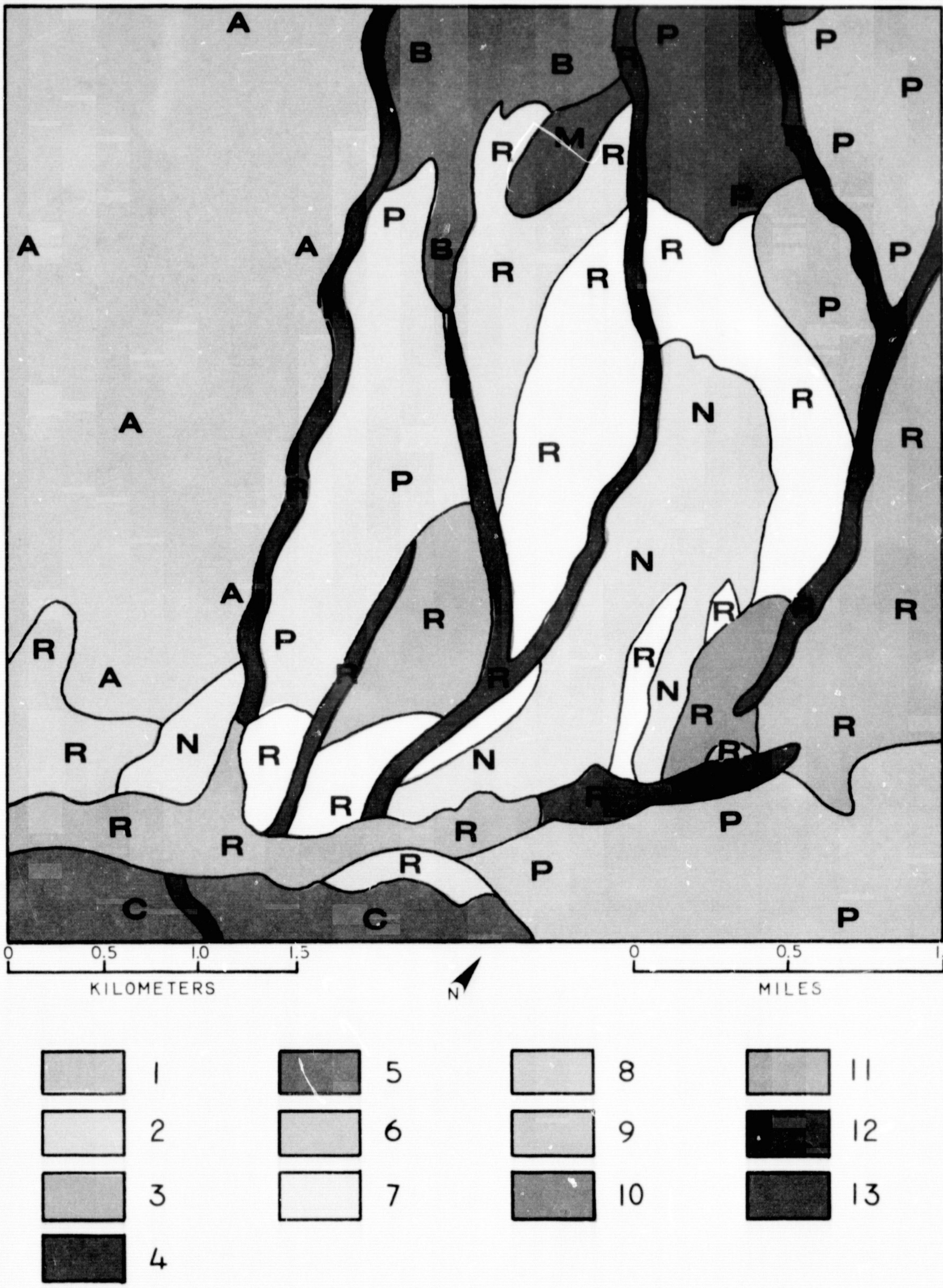


FIGURE 10. PLANT COMMUNITIES AND SOILS DEFINED IN THE FIELD FOR SITE 1, ARIZONA.

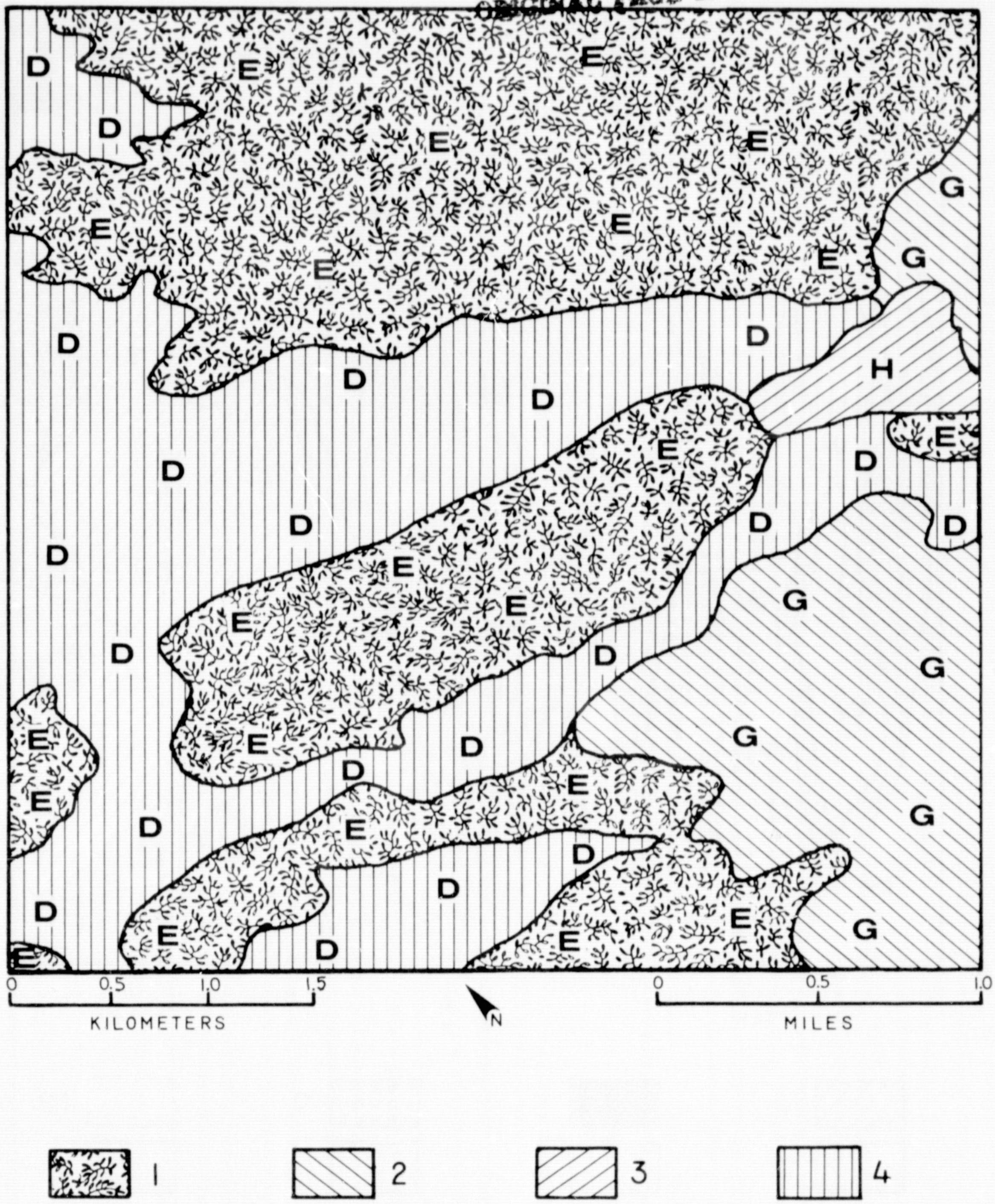


FIGURE 11. PLANT COMMUNITIES AND SOILS DEFINED IN THE FIELD FOR SITE 2, ARIZONA.

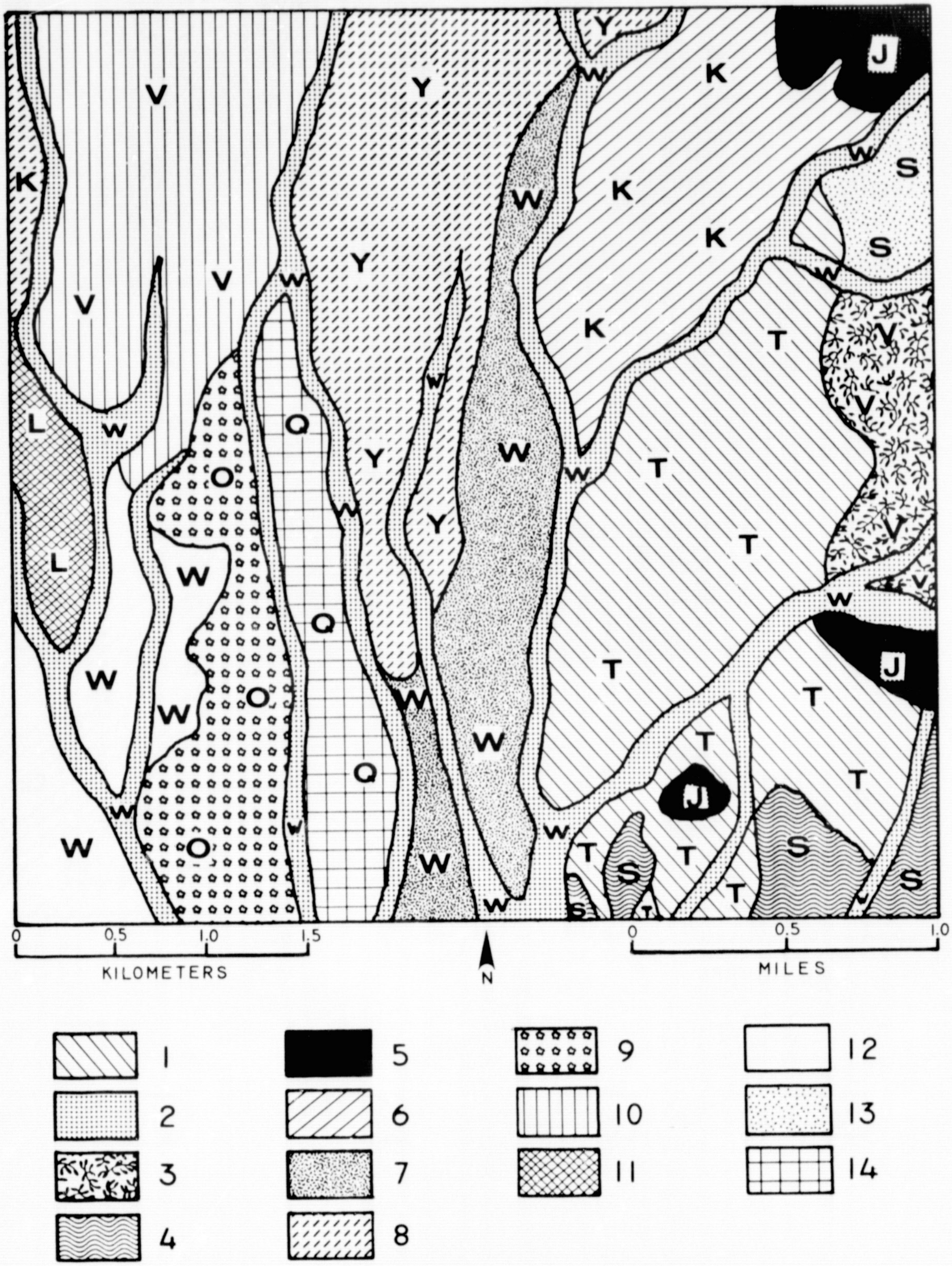


FIGURE 12. PLANT COMMUNITIES AND SOILS DEFINED IN THE FIELD FOR SITE 3, ARIZONA.

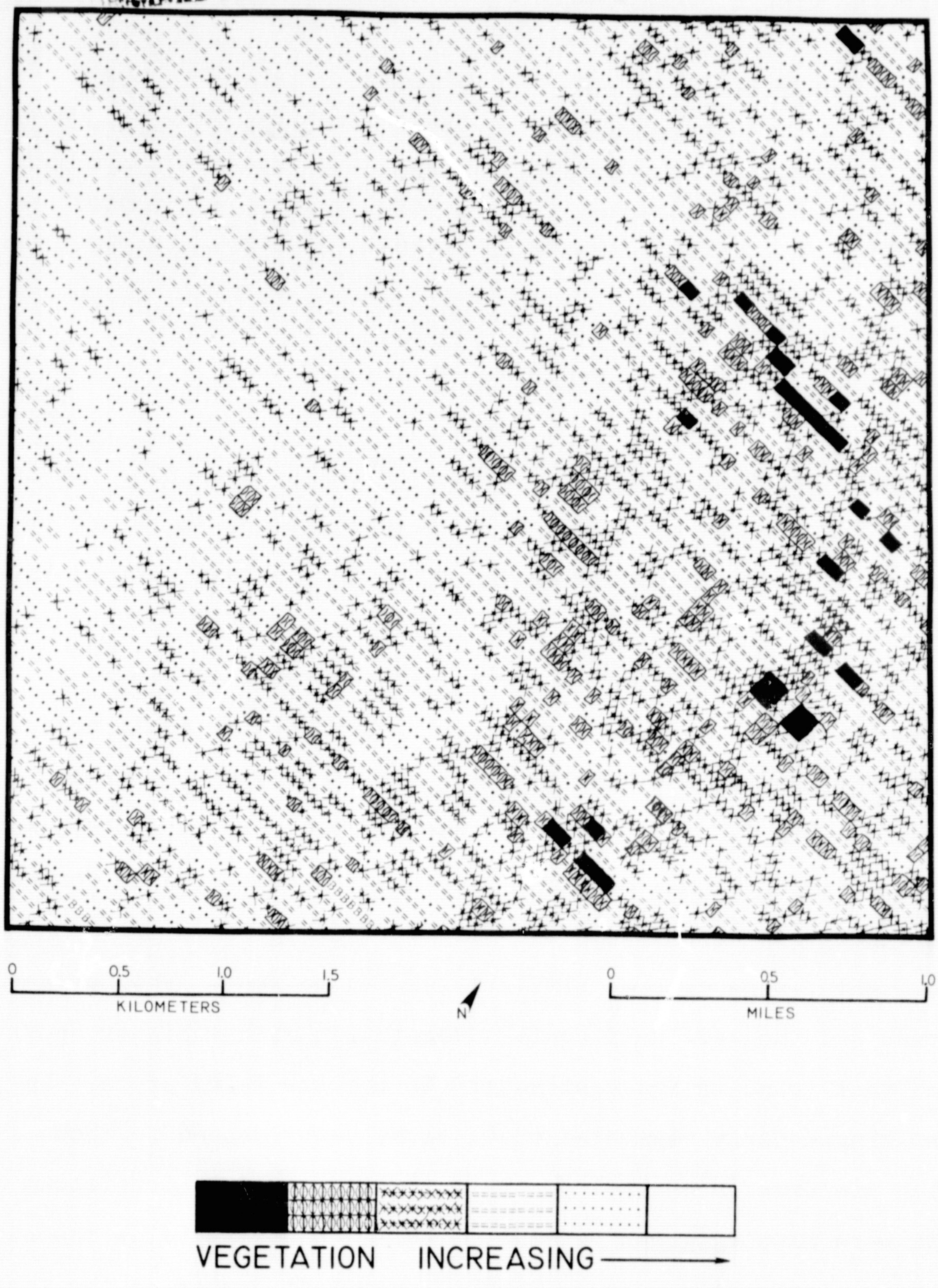


FIGURE 13. VEGETATION COVER AS RECOGNIZED IN LANDSAT $R_{7,5}/R_{5,4}$ FOR SITE 1, ARIZONA (COMPARE WITH FIGURE 10).

TABLE 16. LINEAR REGRESSION RESULTS FOR ENHANCEMENT OF VEGETATION IN ARIZONA, DATE 2 (MAY 20, 1975).

Spectral Parameter	Signif	R^2	SE
Channel 5 (Extracted)	.0203	.184	4.851
Channel 5 (Theoretical)	.3826	.026	5.911
$R_{7,5}/R_{5,4}$ (Extracted)	.0102	.220	4.742
$R_{7,5}/R_{5,4}$ (Theoretical)	.7440	.004	5.977

Signif = Significance
R^2 = Coefficient of determination
SE = Standard Error

and extracted data of Arizona collected on May 20, 1975. It is evident by the low R^2 values that neither product is actually correlated to the percent vegetation cover that was defined in the field work.

Field data is based upon one transect per plant community and transects were long enough to cross several of the small areas differentiated on the LANDSAT data. Before any of the areas identified in $R_{7,5}/R_{5,4}$ could be verified, transects would need to be run within the new boundaries created. However, when comparing the vegetation density map for Site 1 (see Figure 13) with the field data, some general similarities can be seen. The northern corner and the west half contain vegetation with a higher density than that found in the east half. In the low lying areas, the resulting densely vegetated areas closely correspond to those areas which are dark in channel 5. This finding would be consistent if both were mapping green vegetation well. However, below the wash running northeast-southwest in the lower left corner of the test site is an area of dark soils. In channel 5 this is a solid, dark area, appearing to be rocks or soil of a distinct type from those of the rest of the area. In the vegetation mapper, however, this area shows only average to slightly more than average vegetation cover. It is not clear what effects are more important in this area, the very low reflectance of the rock or the vegetation cover present.

MSS channel 5, when viewed independently, appears to be discriminating a combination signature made up of land form and topography, soil particle size (sand, clay), soil surface texture (size and percent of rock cover), and vegetation. Field observations of boundaries of plant communities showed that species composition and percent of ground covered by live vegetation, characteristics which determine the identity of a community, are influenced by physical aspects of a site. Vegetation transect data (see Appendix A) indicate that, with a few exceptions, plants found on one Arizona test site can also be found on the other two sites. The exceptions are mostly confined to the north facing slopes (see Figure 11) of Site 2. These plants do, in addition, make up a very small percentage of the species composition of communities on Site 2. Vegetation transect data also show the variations in species composition and percent vegetative ground cover which differentiate one plant community from another; the differences between plant communities are sometimes very small, and some plant communities are similar from site to site.

The results of level slicing of channel 5 data conform in a general way to plant community boundaries prepared from field data. Plant communities have not been uniquely recognized in this channel. A group of several communities have often been classified together in one slice of channel 5, as shown on graymaps shown in Figures 14, 15 and 16. Plant community signatures, as shown in Figure 17, using values extracted from LANDSAT data, illustrate the difficulty in discriminating vegetation alone. The values for each community varied more within a community than values between communities. Variation within a soil unit (see Figures 10, 11 and 12) was also greater than between different soil units.

On Site 1, the channel 5 graymap (Figure 14) has identified several outwash plains, raised fingers of land lying across the northern portion of the site, as well as a series of low hills along the west half and southern corner. Several large blocks of the most densely populated plant communities outlined on the field data (see Figure 10) fall directly over these features. Transect data in Appendix A show percent ground cover to range from 9 to 18 percent. The overgrazed sandy area in the eastern portion of the site has been correctly shown as having less plant cover; transect data show percent ground cover here to range from 3 to 8 percent.

The dense population of mesquite, 24 percent, growing in a flat, wide sandy wash in the southern part of the test site, has not been separated from the surrounding sandy creosote bush benches. The creosote bush communities to the north and northeast fall into the 5 to 8 percent ground cover category. The subtle

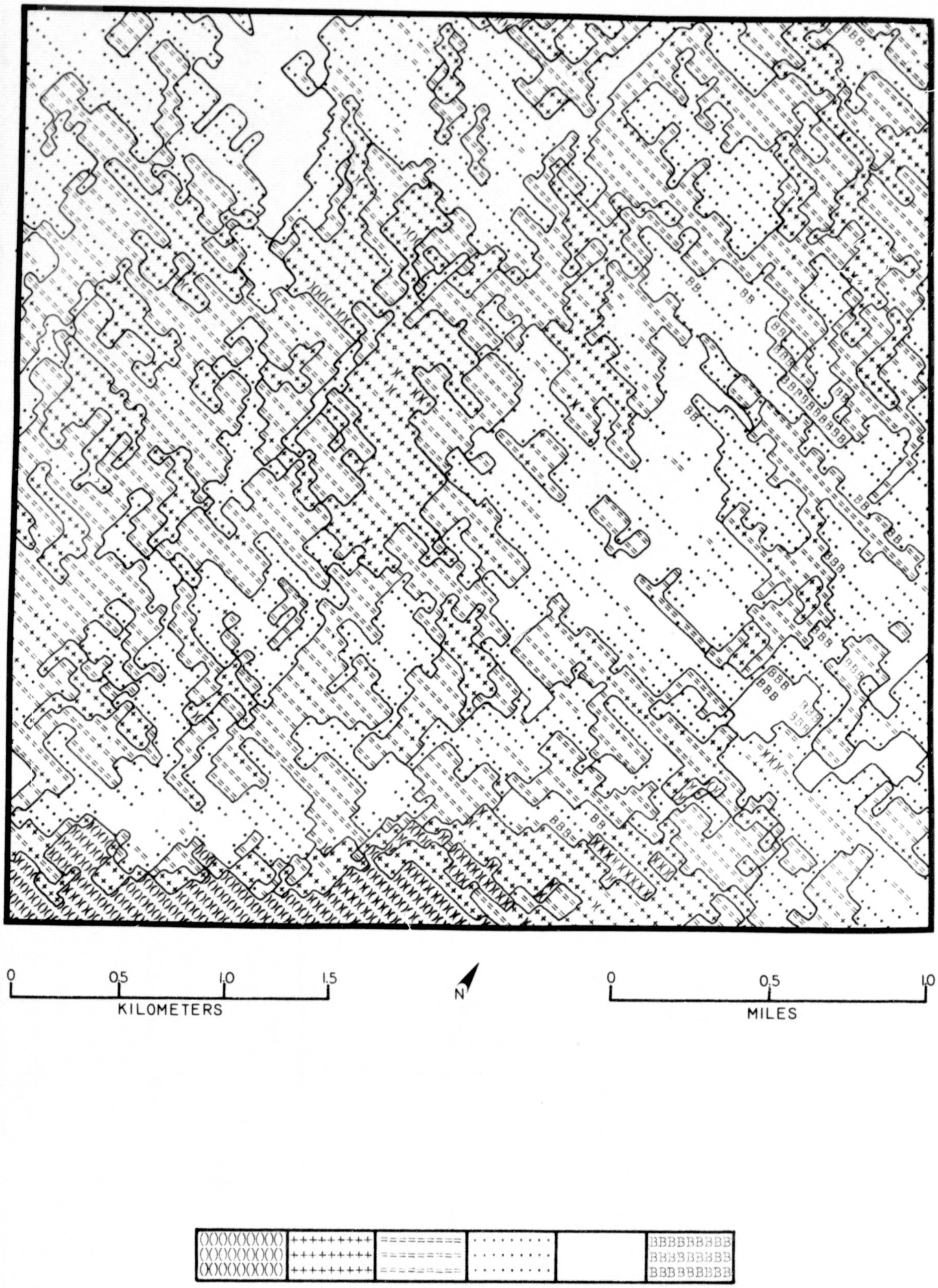
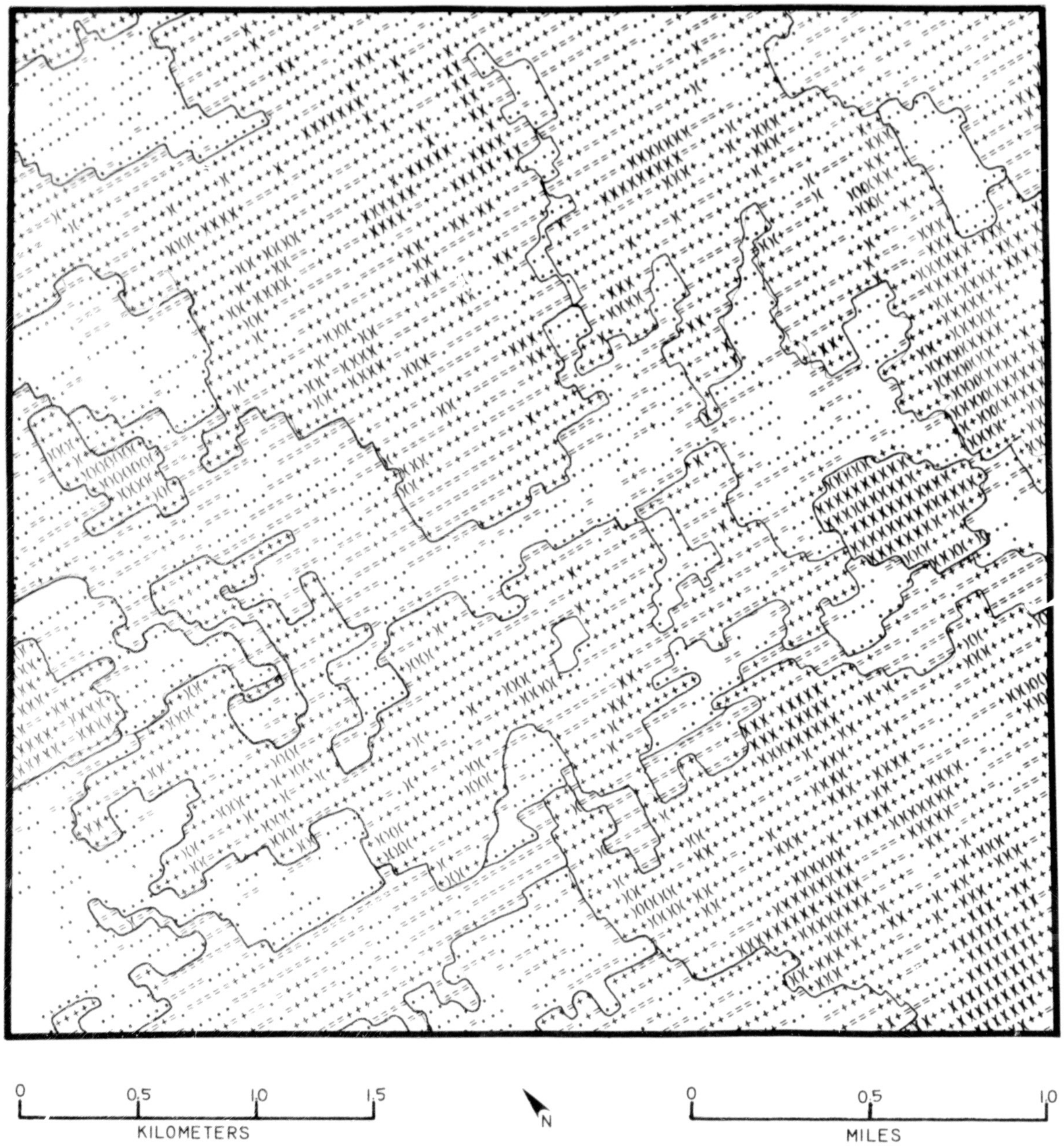


FIGURE 14. SIX LEVEL DENSITY SLICE OF MSS CHANNEL 5 FOR SITE 1, ARIZONA (COMPARE WITH FIGURE 10).



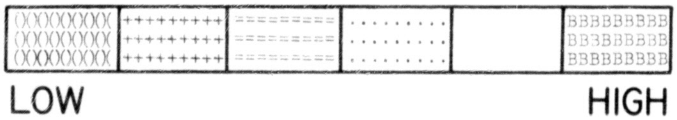


FIGURE 15. SIX LEVEL DENSITY SLICE OF MSS CHANNEL 5 FOR SITE 2, ARIZONA (COMPARE WITH FIGURE 11).

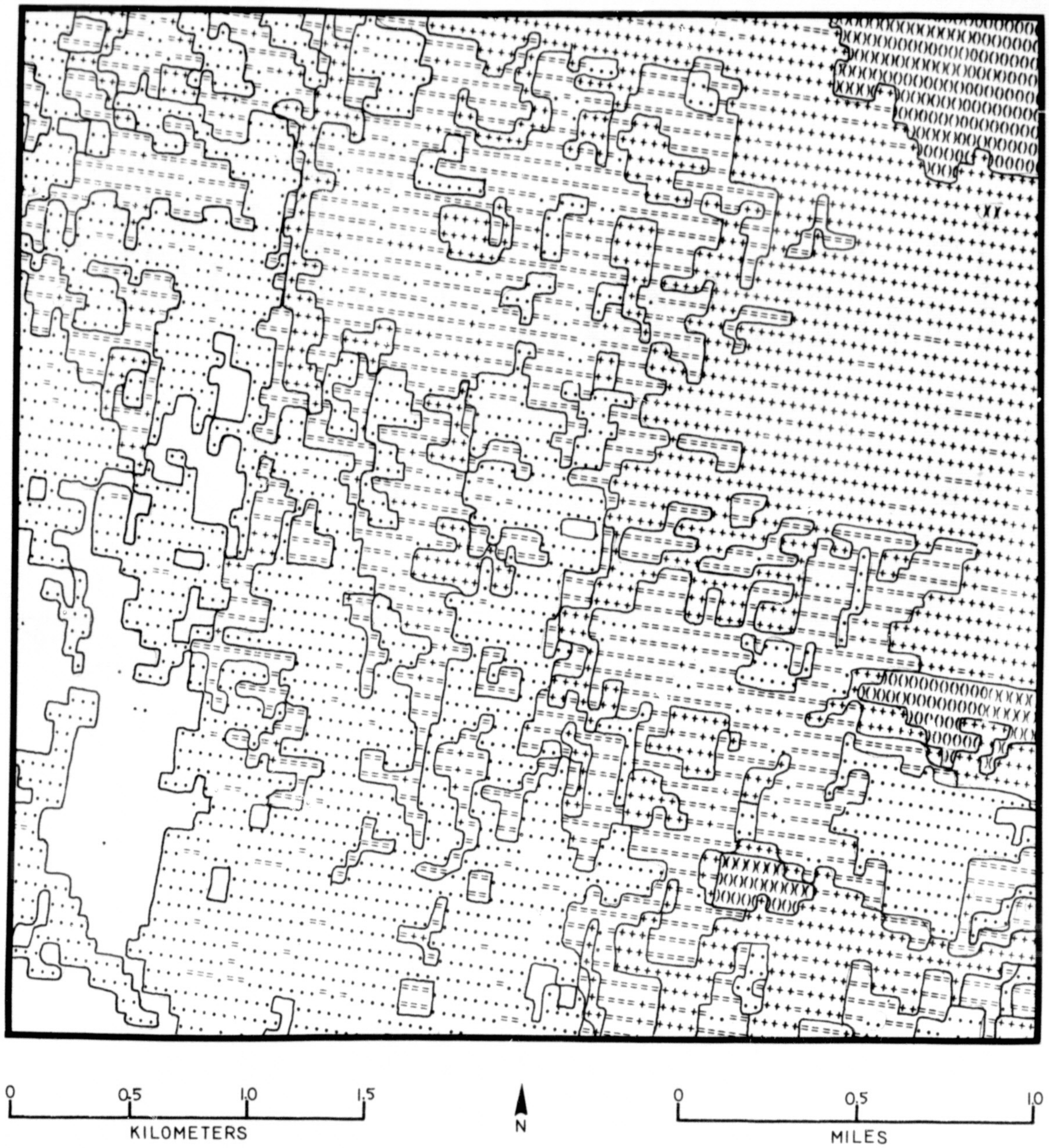


FIGURE 16. SIX LEVEL DENSITY SLICE OF MSS CHANNEL 5 FOR SITE 3, ARIZONA (COMPARE WITH FIGURE 12).

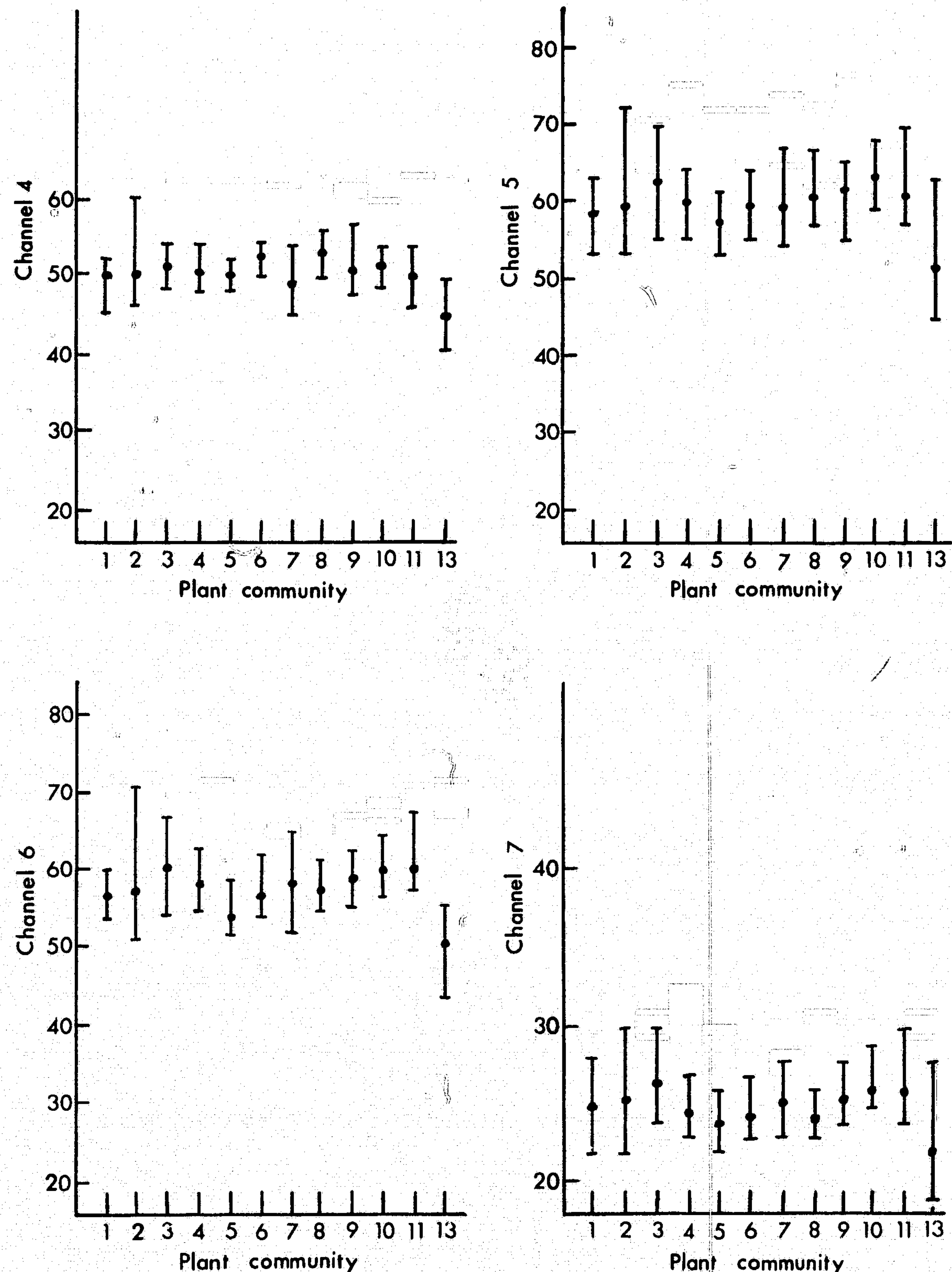


FIGURE 17. ARIZONA SITE 1 PLANT COMMUNITY SIGNATURES FOR LANDSAT CHANNELS, DATE 2 (MAY 20, 1975).

differences in species composition which separate the plant communities falling within a given range of percent ground cover, i.e., 3 to 8 or 9 to 18 percent, have not been recognized by the satellite data. It appears that differences in topography, geology or soil types are the dominant features being seen. For instance, the sandy benches and broad sandy wash could not be separated even though there was a difference of 16 percent in plant cover.

On Site 2 (Figure 15) the various areas classified by channel 5 correspond rather closely to the vegetative community boundaries drawn from field data. This is probably due to the fact that the vegetative boundaries were drawn along geologic formation and topographic features. For instance, two large ridges of mountains lying laterally across the area have been shown as separate from the two valleys that lie between the mountains. A slight geologic difference seen in the southeast corner of the site (Plant Community 4) did not show up on the channel 5 image. It appears that Plant Community 4 is very similar to Plant Community 2.

Mapping Site 3 with channel 5 (Figure 16), the ability to classify plant communities produced results similar to the other two sites, especially to Site 1. The very dark geologic features, or volcanic (andesite) mountains, in the northeast and southeast corners were misclassified as having very dense vegetation, when in fact the percent plant ground cover was 12 percent. Channel 5 was able to distinguish the upland rolling hills with gravelly sandy loam soil in the northeast and east central portions of the test site from the low lying sandy loam outwash plains in the north central and northwestern portions, and these areas from the sandy areas in the central, south central and southwestern portions of the site. Plant communities identified from field data correspond generally to these topographic and soil features.

5.2 Perennial Rangeland in Montana

Site maps with plant communities defined during field work prepared from aerial photomosaics are presented in Figures 18-20. Although the test sites were originally delimited to correspond to section line boundaries, it is apparent that there is considerable misalignment from one section to the other in these maps because of parallax in the photographs. The use of these photomosaics for a data base created a considerable problem in accurate location of plant communities on the LANDSAT data. Somewhat subjective fitting of the data to overcome local distortions in the plant community base map probably introduced a slight bias in correlation results. The site maps as they are presented here, were adapted from the original base maps to more accurately fit the LANDSAT products' geometry and scale. Without this procedure, changes in plant communities and topography over small regions could not have been evaluated at all.

Before discussing the interpretation of individual LANDSAT enhancement products, we present a summary of simple linear regressions run for theoretical and empirical data as shown in Table 17. In addition to the results for predicting percent

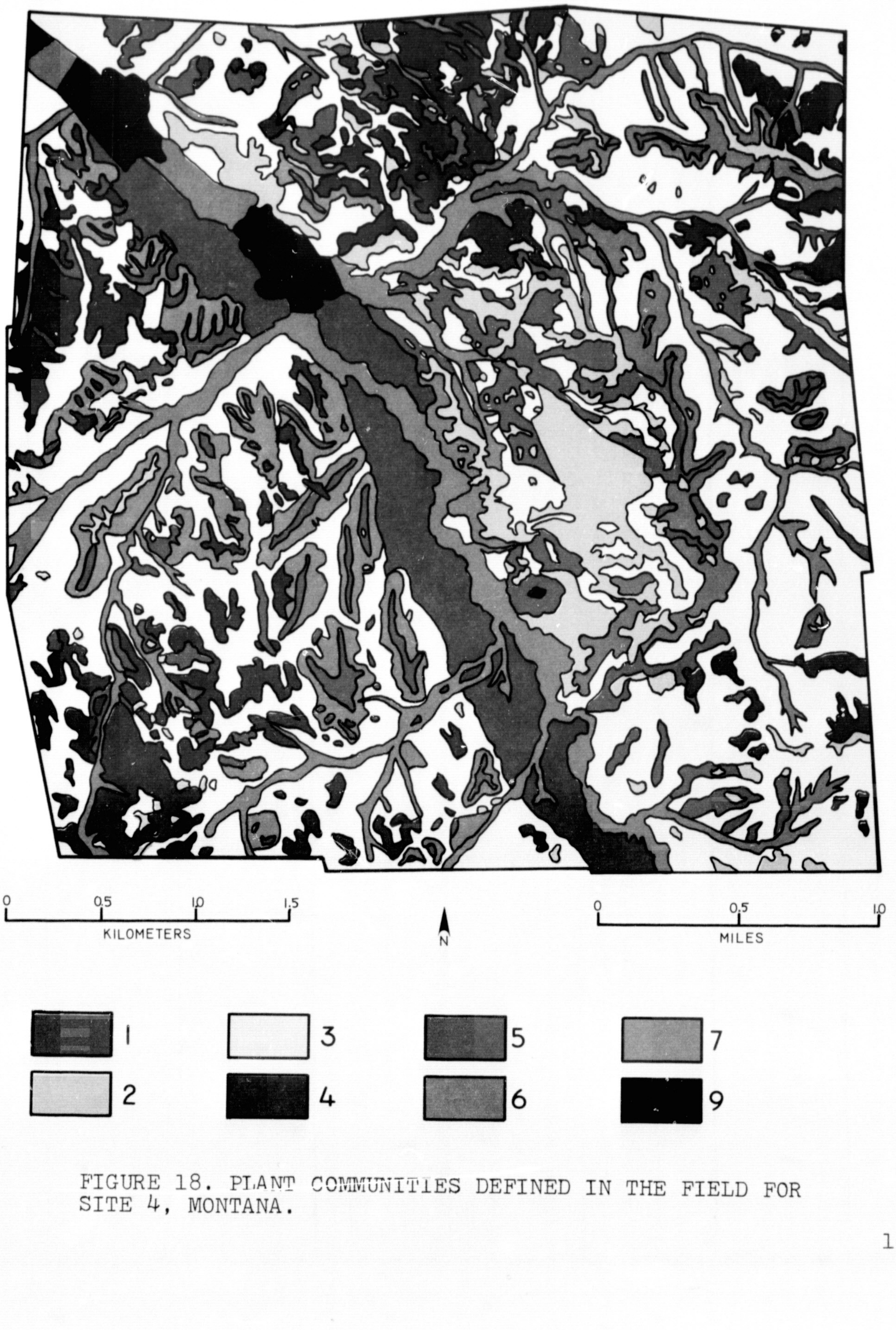


FIGURE 18. PLANT COMMUNITIES DEFINED IN THE FIELD FOR SITE 4, MONTANA.

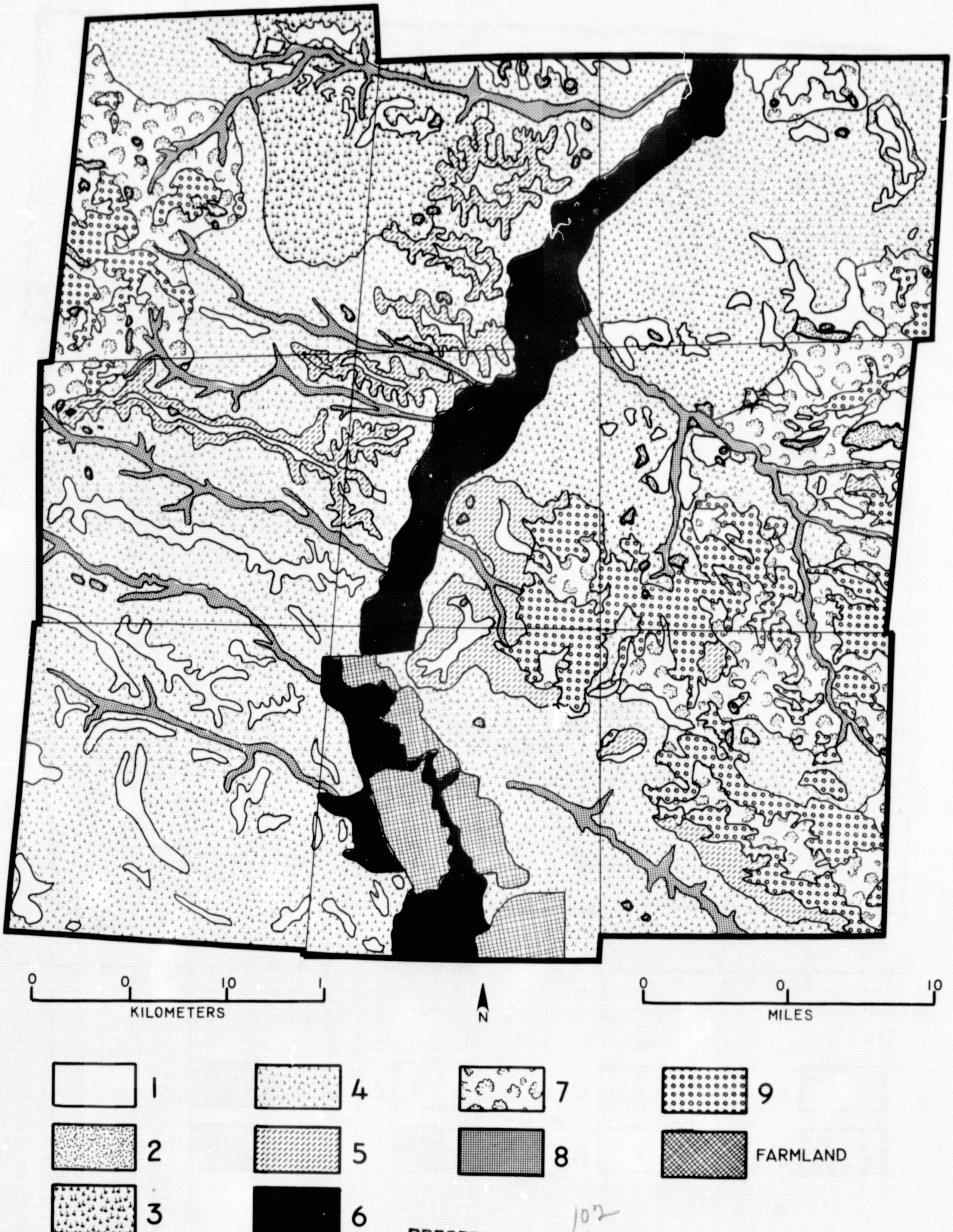


FIGURE 19. PLANT COMMUNITIES DEFINED IN THE FIELD FOR SITE 5, MONTANA.

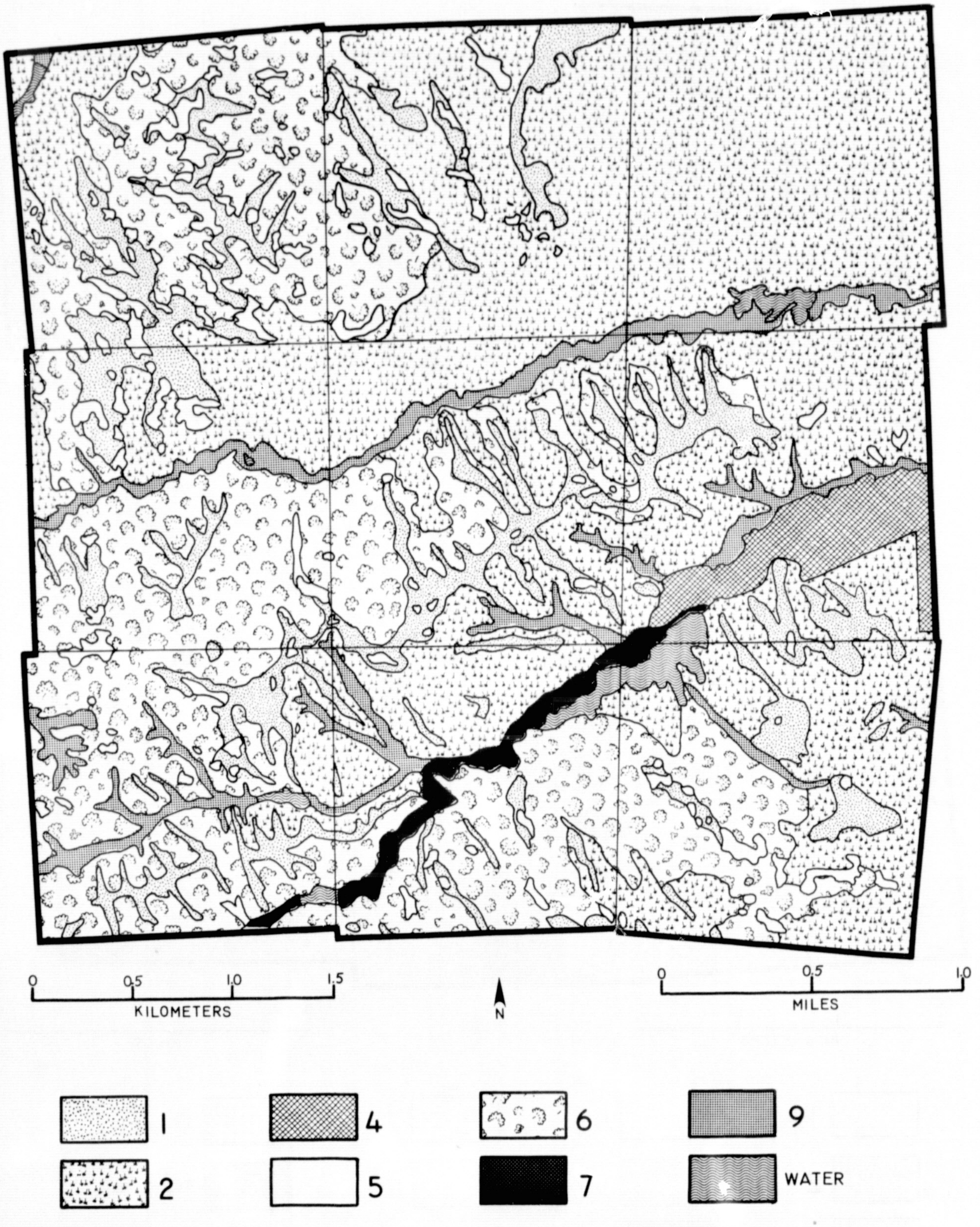


FIGURE 20. PLANT COMMUNITIES DEFINED IN THE FIELD FOR SITE 6, MONTANA.

TABLE 17. SIMPLE LINEAR REGRESSION OF LANDSAT DATA WITH PERCENT VEGETATION IN MONTANA.

June 23, 1975

Spectral Parameter		Signif	R^2	SE
Channel 5	(Extracted)	.0001	.46604	12.6730
Channel 5	(Theoretical)	.0000	.77184	8.4151
$R_{7,5}$	(Extracted)	.0005	.39884	13.4470
$R_{7,5}$	(Theoretical)	.0001	.53922	11.9590
Model	(Extracted)	.0029	.57260	12.4400
Model	(Theoretical)	.0000	.93138	5.0209

August 1, 1975

Spectral Parameter		Signif	R^2	SE
$R_{7,5}$	(Theoretical)	.0000	.72147	8.9012

Signif = Significance
R^2 = Coefficient of determination
SE = Standard Error

vegetation for the date of June 23, 1975, we include one result from data collected on August 1, 1975. The improvement in theoretical $R_{7,5}$ data from June 23 to August 1 suggests that an improvement could be made with the ratioing of LANDSAT data collected on that later date.

Three of the plant communities with extreme vegetation differences on Site 4 have been segregated from the field map in Figure 21, and from the enhancement products in Figures 22 to 25. The alfalfa fields in the area do not appear more green in the color photomosaics than some of the well-watered bottomland. They are, however, the most densely vegetated areas in the scene (70 percent

FIGURE 21. FIELD MAP SHOWING PLANT COMMUNITIES WITH EXTREMES OF VEGETATION IN SITE 4, MONTANA.

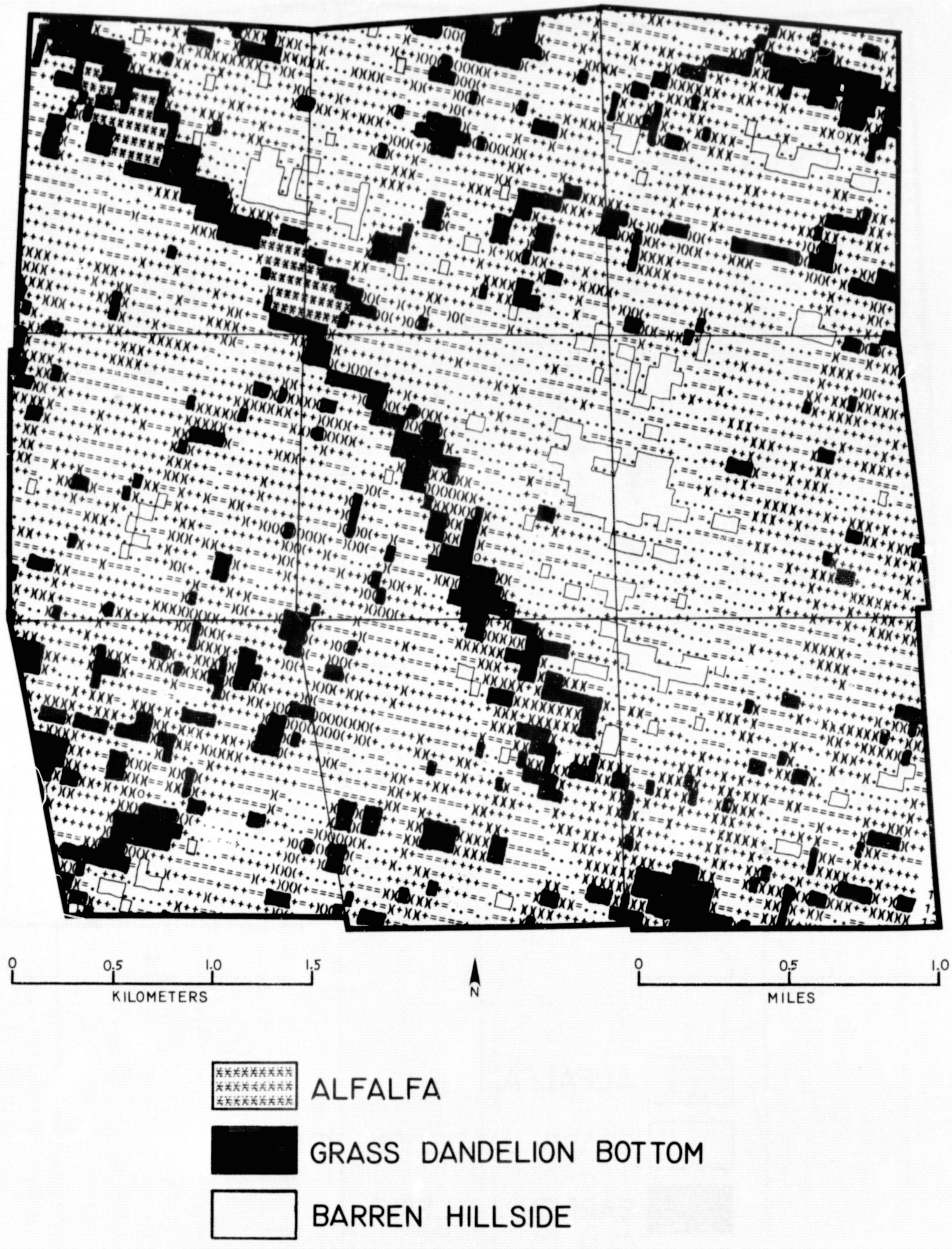


FIGURE 22. MSS CHANNEL 5 SHOWING PLANT COMMUNITIES WITH EXTREMES OF VEGETATION IN SITE 4, MONTANA.

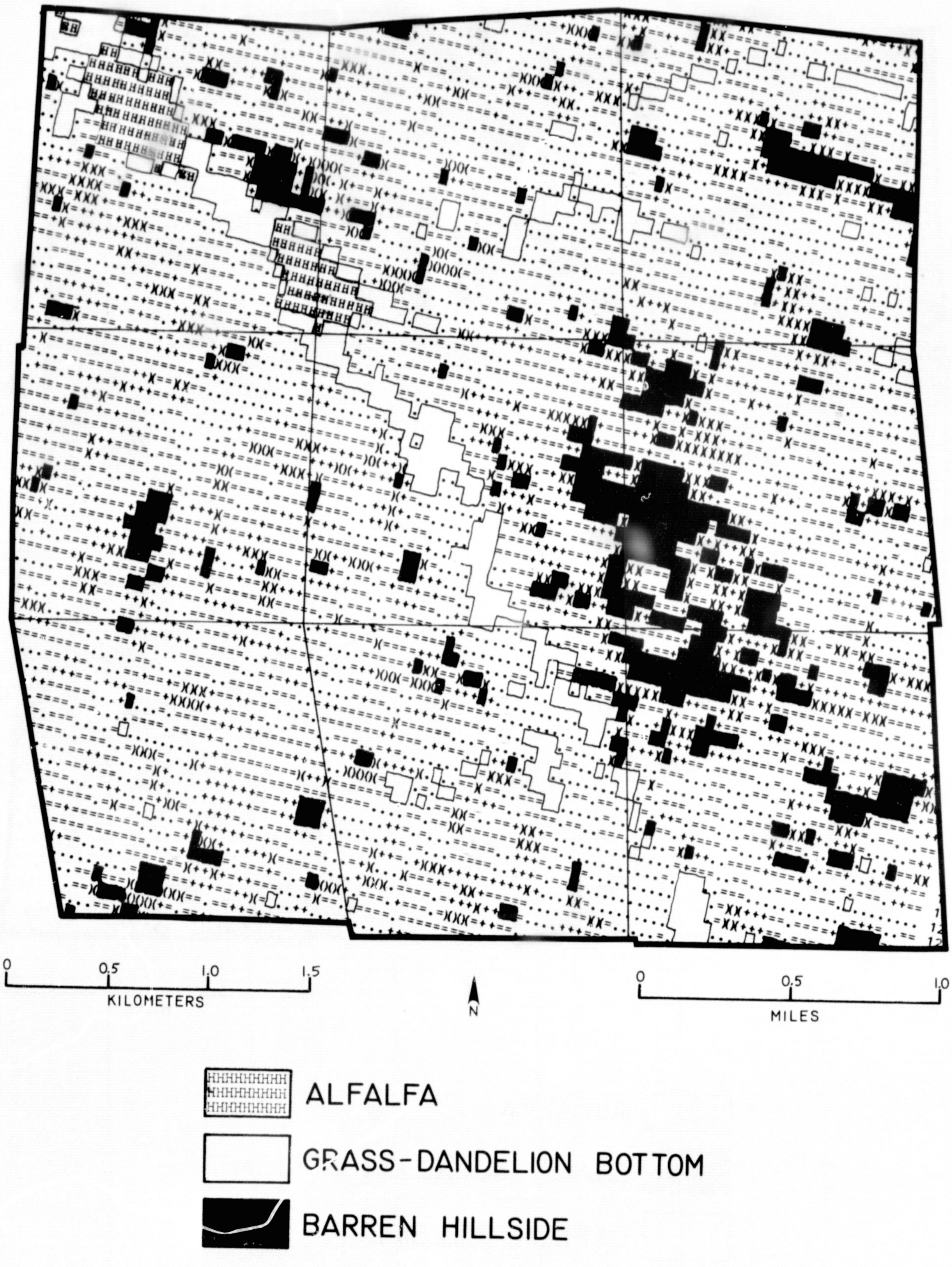


FIGURE 23. $R_{7,5}$ SHOWING PLANT COMMUNITIES WITH EXTREMES OF VEGETATION IN SITE 4, MONTANA.

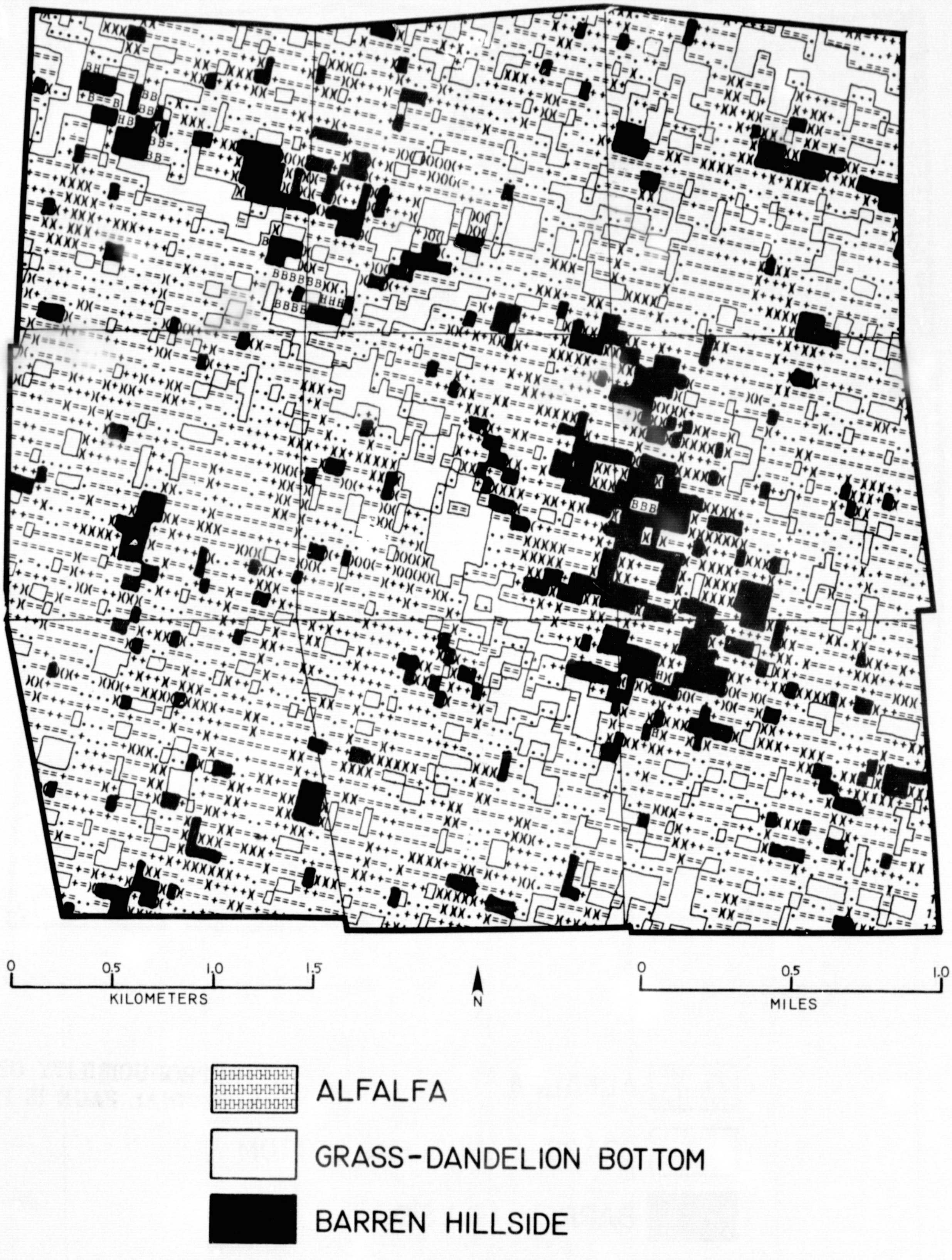


FIGURE 24. EMPIRICAL MODEL SHOWING PLANT COMMUNITIES WITH EXTREMES OF VEGETATION IN SITE 4, MONTANA.

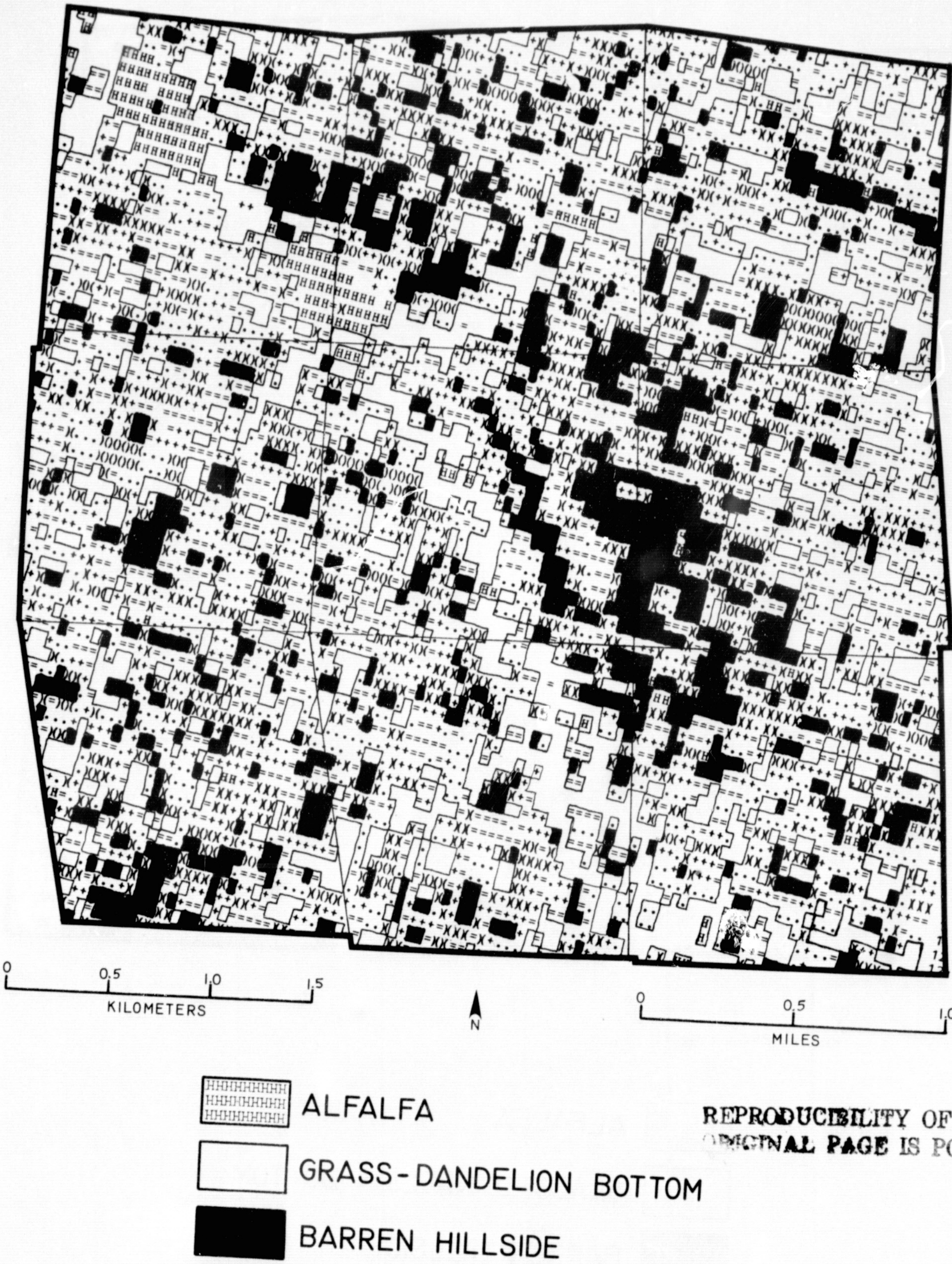


FIGURE 25. THEORETICAL MODEL SHOWING PLANT COMMUNITIES WITH EXTREMES OF VEGETATION IN SITE 4, MONTANA.

ground cover) according to field transect data. The alfalfa fields were easily differentiated from the rest of the scene on all four enhancement products. In the theoretical model (see Figure 25) some additional points of high vegetation are also found scattered about the scene. Some of these do appear to be in other areas of very vigorous vegetation; it is not clear that all of them are.

The next most dense areas of vegetation on Site 4 are the grass-dandelion bottom areas with reportedly 53 percent ground cover. Most often, there was little difference between these areas and well-watered areas of the adjoining silver sage-grass bottom where excess water from flooding by overland flow followed periods of spring snowmelt and summer thundershowers. This result in the data is compatible with field work which indicated that parts of the silver sage-grass bottom have 52 percent vegetation cover. Narrow areas of dense vegetation were less evident on the $R_{7,5}$ product than on other LANDSAT products. Those areas field-mapped as grass-dandelion bottom in the narrow valleys leading down to Liscom Creek are not mapped in the same level slice of $R_{7,5}$ as are the broader areas along the creek, indicating probable signature mixing due to inadequate spatial resolution.

On Site 4, the areas with the least vegetation were designated as barren hillside (15 percent ground cover) and a coal mine fire rehabilitation area (16 percent ground cover). These two plant communities are being treated together in this report and are designated as Plant Community 2, barren hillside. The barren hill-side areas of this site were recognized by all products, although ratio products seem to have been more sensitive to smaller areas. In addition, within the broad coal mine fire rehabilitation area, differences in vegetation, which had been assumed to be insignificant during field work, can actually be seen on all of the LANDSAT products.

Pine-bunchgrass areas in this site have 57 percent ground cover. Any product showing percent vegetation should include areas of pine-bunchgrass in their highest vegetation levels for Site 4. In fact, some of the stands are correctly included as areas of high vegetation, particularly in channel 5. However, reevaluation of the pine-bunchgrass stands on aerial photographs showed that there are noticeable differences in the density of individual stands. Although pine stands were not always unique in the channel 5 product, known differences in density correlated with the expected differences in gray levels, again most recognizably in channel 5. Pine-bunchgrass, although having a high percent ground cover, differs from other highly vegetated plant communities in the infrared. Pine needles are not very reflective at any wavelength. For this reason, it is somewhat fortuitous that channel 5 appears to truly see pine-bunchgrass areas at 57 percent ground cover; in actuality it may be showing more textural information than percent vegetation. Indeed, in spite of its high percent vegetation cover, Plant Community 4, pine-bunchgrass, on Site 4 had the lowest mean radiance of all eight plant communities on channels 6 and 7.

While in channel 5, pine-bunchgrass was similar to grass-dandelion bottom, on the single ratio $R_{7,5}$ pine-bunchgrass is more similar to Plant Community 1, silver sage-grass bottom which also overlaps with grass-dandelion bottom. These three plant communities, along with areas of upland grass, appear similar enough in percent cover to be seen as similar within our ability to evaluate $R_{7,5}$ and the predictive models. Figures 26 and 27 show the pine-bunchgrass and silver sage-grass bottom communities, as determined in the field, superimposed on LANDSAT data. It can be noted that the areas of silver sage-grass bottom in the northwest near the alfalfa fields are shown on MSS channel 5 to be much less vegetated than those areas further southeast. This difference is probably due to differences in soil depth and water availability; the areas to the northwest are slightly raised above the valley bottom. The southwestern edge of this plant community is shown as sparse vegetation (light in channel 5 and dark in the theoretical model) reflecting the presence of a road that follows along the valley edge.

The most extensive and widely distributed plant community is the upland grass with 46 percent ground cover. Limited field data indicated that ground cover over this broad community was fairly constant. However, a close examination of the aerial photographs reveals a varied topography (rolling hills, gentle slopes, and small valleys), which would lead one to suspect that there could be considerable variation in the actual vegetation cover. In addition, bluestem hillsides, Plant Community 6, had 47 percent cover, and therefore should look nearly identical in spectral products correlating with percent vegetation cover, especially in ratio

FIGURE 26. MSS CHANNEL 5 SHOWING THE SILVER SAGE-GRASS BOTTOM AND PINE-BUNCHGRASS PLANT COMMUNITIES FOR SITE 4, MONTANA.

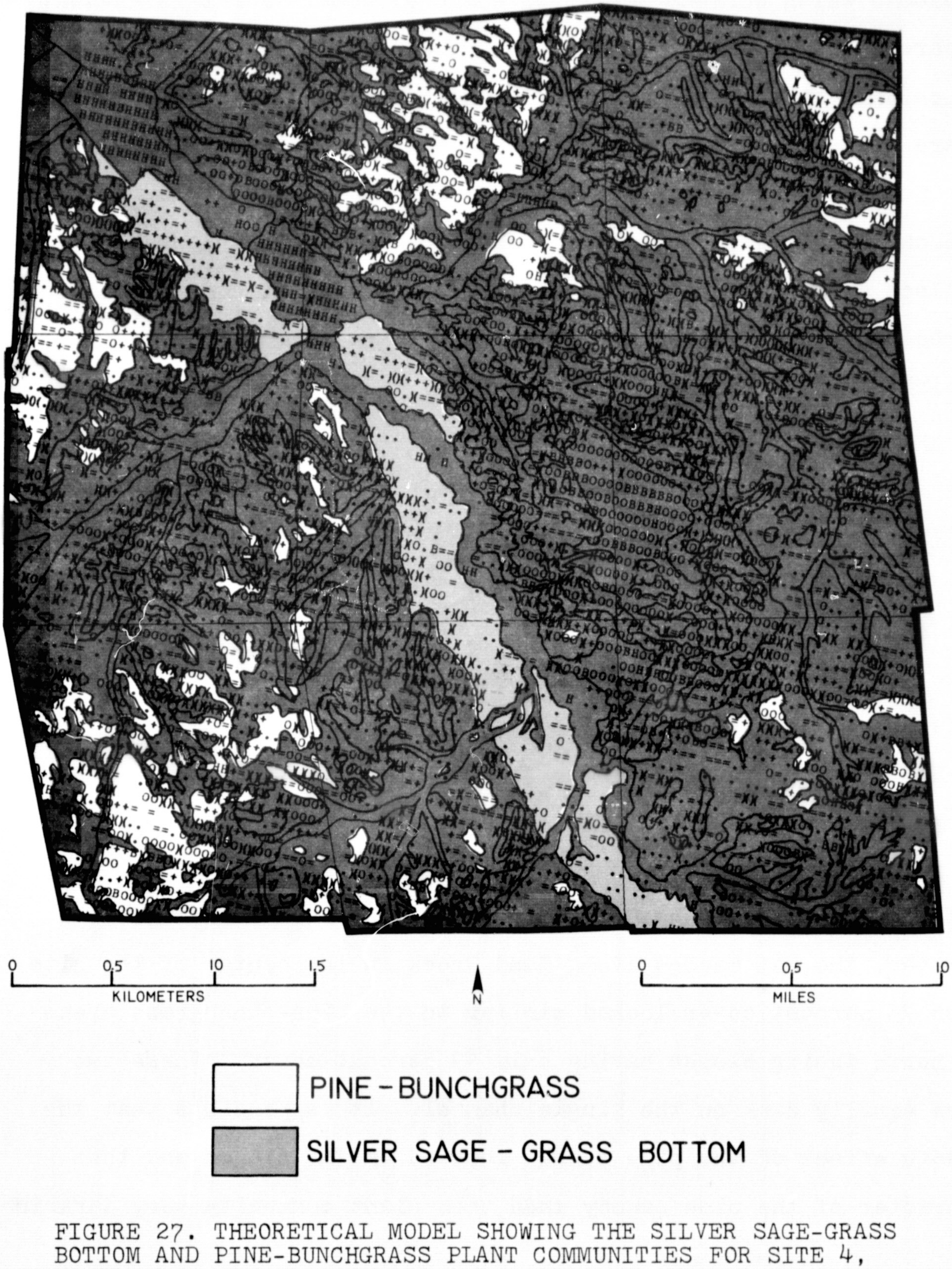


FIGURE 27. THEORETICAL MODEL SHOWING THE SILVER SAGE-GRASS BOTTOM AND PINE-BUNCHGRASS PLANT COMMUNITIES FOR SITE 4, MONTANA.

products which correct for topographic effects. For this reason, apparent differences between upland grass and bluestem hillside which were chiefly topographical were best seen on MSS channel 5 where topography is most evident. Compare the resolution of these two plant communities on Figures 28 and 29. Darker map symbols in MSS channel 5 (Figure 28) often show that bluestem hillsides do not reflect as much energy as the flatter upland grass community. Symbols are more random across the two plant communities in the empirical predictive model, (Figure 29) indicating less influence of topography, and apparently more natural variation in vegetation cover than had been perceived by the field worker. Small barren areas, less than an acre in size influenced the signature of the grass community. The small lateral valley in the southwestern quadrant of Site 4 contains several barren eroded stream banks which show up on both the aerial photomosaic and channel 5. Greater detail of barren areas can be seen through Site 4 on LANDSAT data, separating these from deeper soils in depressions and narrow drainage channels which support more vegetation.

On Site 5 the MSS channel 5 of LANDSAT was again able to differentiate very dense vegetation from the most barren areas. However, the wet meadow along Sand Creek in the center of the site with 75 percent cover looked similar to the pine-bunchgrass areas on north facing slopes having only 59 percent cover. These two were equally dark on the single channel. It is possible that the shadow effect of the pine stands located on the slopes and the character of the pine canopy made this plant community very dark in

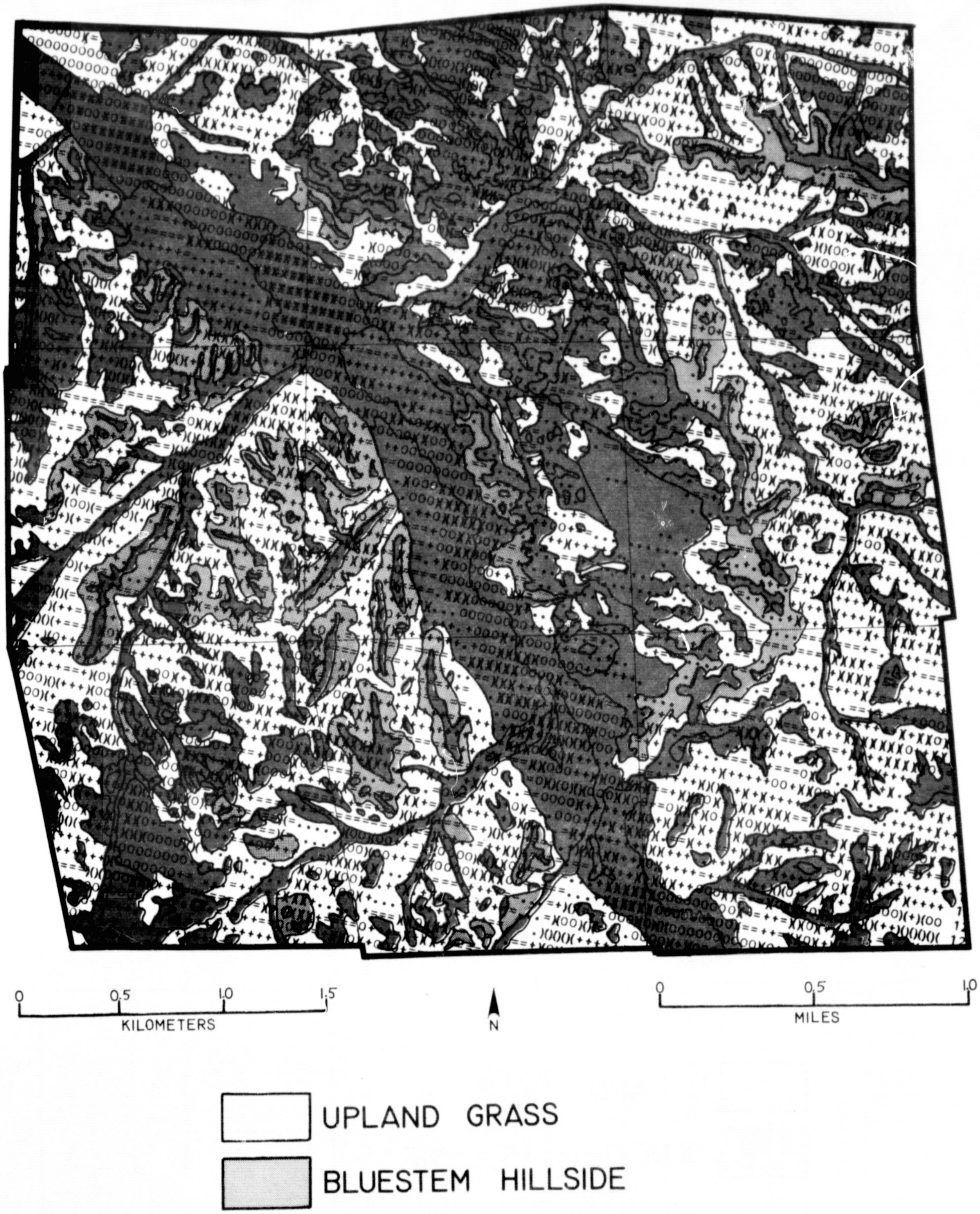


FIGURE 28. MSS CHANNEL 5 SHOWING UPLAND GRASS AND BLUESTEM HILLSIDE PLANT COMMUNITIES FOR SITE 4, MONTANA.

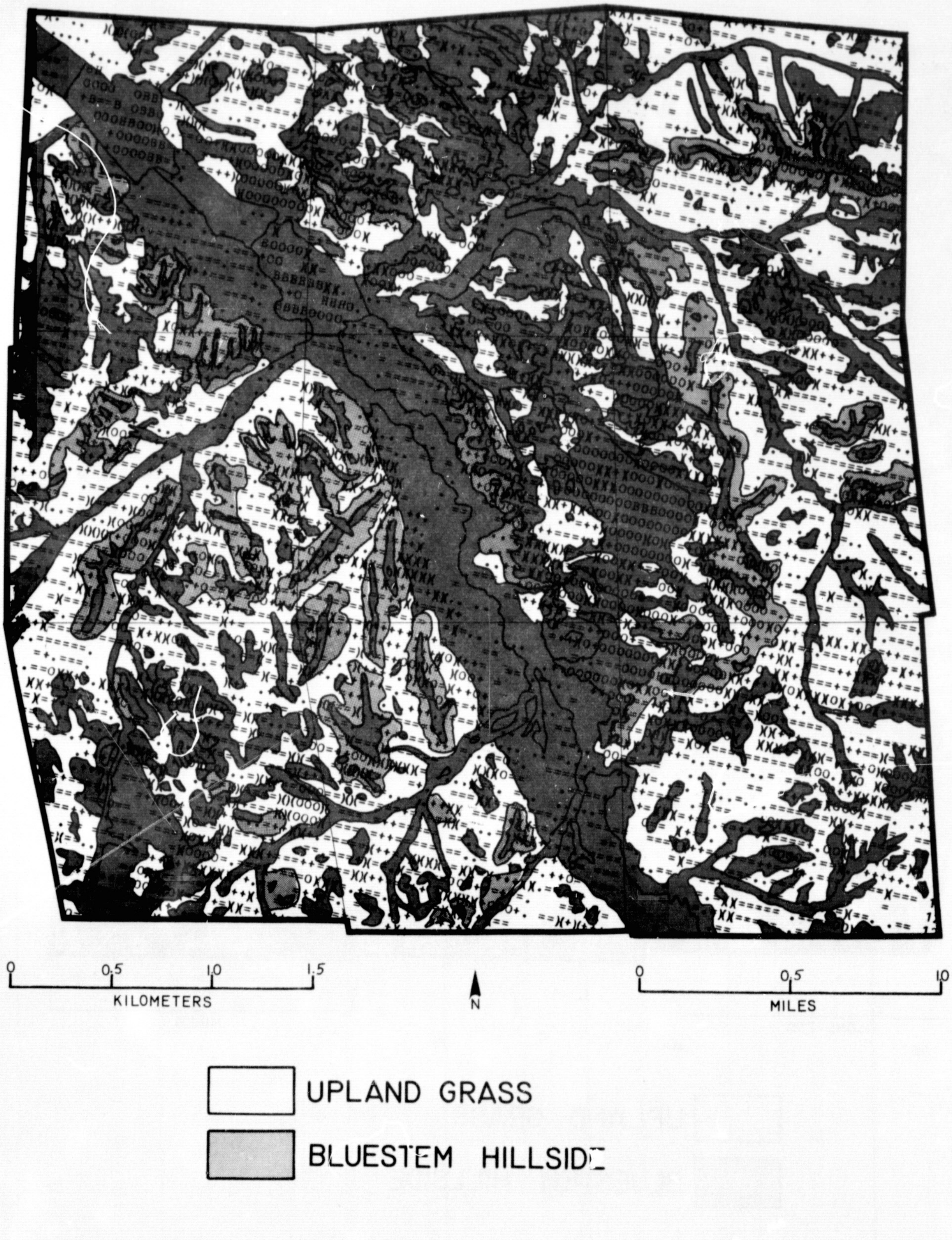


FIGURE 29. EMPIRICAL MODEL SHOWING UPLAND GRASS AND BLUESTEM HILLSIDE PLANT COMMUNITIES FOR SITE 4, MONTANA.

single channel values. Pine-bunchgrass stands on other exposures looked similar to sage-grass upland and grass flat communities. Figure 30 segregates just the wet meadow, silver sage-grass stringer (63 percent vegetation cover) and pine-bunchgrass communities in Site 5 overlaying MSS channel 5. Wet meadow and pine-bunchgrass are the darkest areas in the scene, the silver sage-grass stringers not showing as more heavily vegetated than other plant communities present. Actually, the sage-grass upland (58 percent vegetation cover) is very close to the same percent vegetation as pine-bunchgrass and yet appears much lighter on channel 5. In $R_{7,5}$ (see Figure 31) wet meadow vegetation is seen uniquely as the most vegetated region (along with heavily vegetated farmland). Silver sage-grass stringers are more predominant here than in MSS channel 5, although not strikingly, perhaps due to their narrow spatial configuration. Pine-bunchgrass shows as densely vegetated, but not as dense as it should. It appears similar in percent vegetation cover to the sage-grass uplands in the southeastern part of the site. Both MSS channel 5 and $R_{7,5}$ detected dense green vegetation along the course of the creek made up of ash trees, thick grass, and sedge where water concentrates, which had not been separated in the original definition of the plant community. These areas can be seen as $\underline{X}$ in the map of channel 5 and $\underline{H}$ in $R_{7,5}$.

A local area of Site 5 is shown in all LANDSAT products in Figure 32. There are two features of interest which have been treated differently by the predictive models. In both channel 5

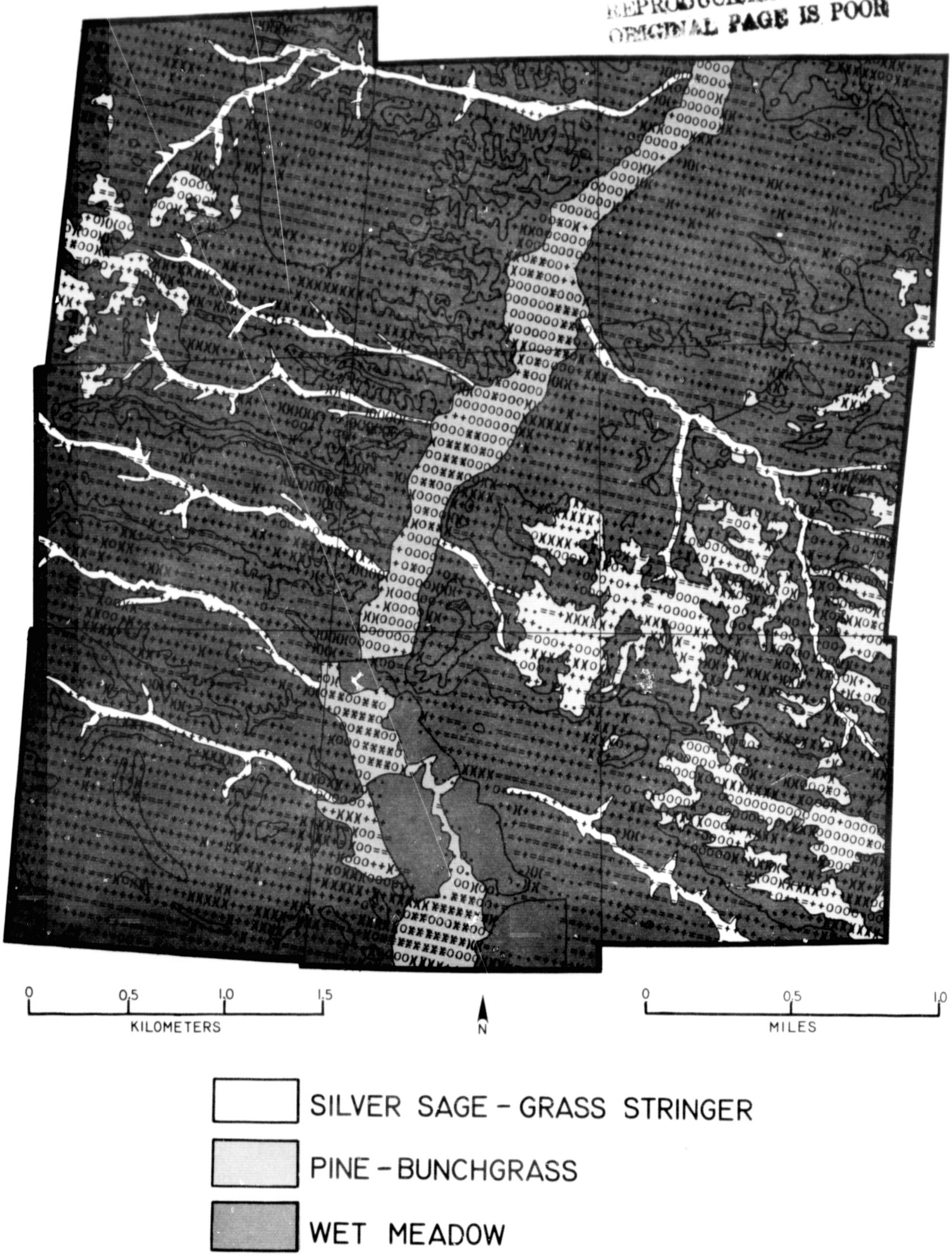


FIGURE 30. MSS CHANNEL 5 SHOWING WET MEADOW, SILVER SAGE-GRASS STRINGERS, AND PINE-BUNCHGRASS PLANT COMMUNITIES FOR SITE 5, MONTANA.

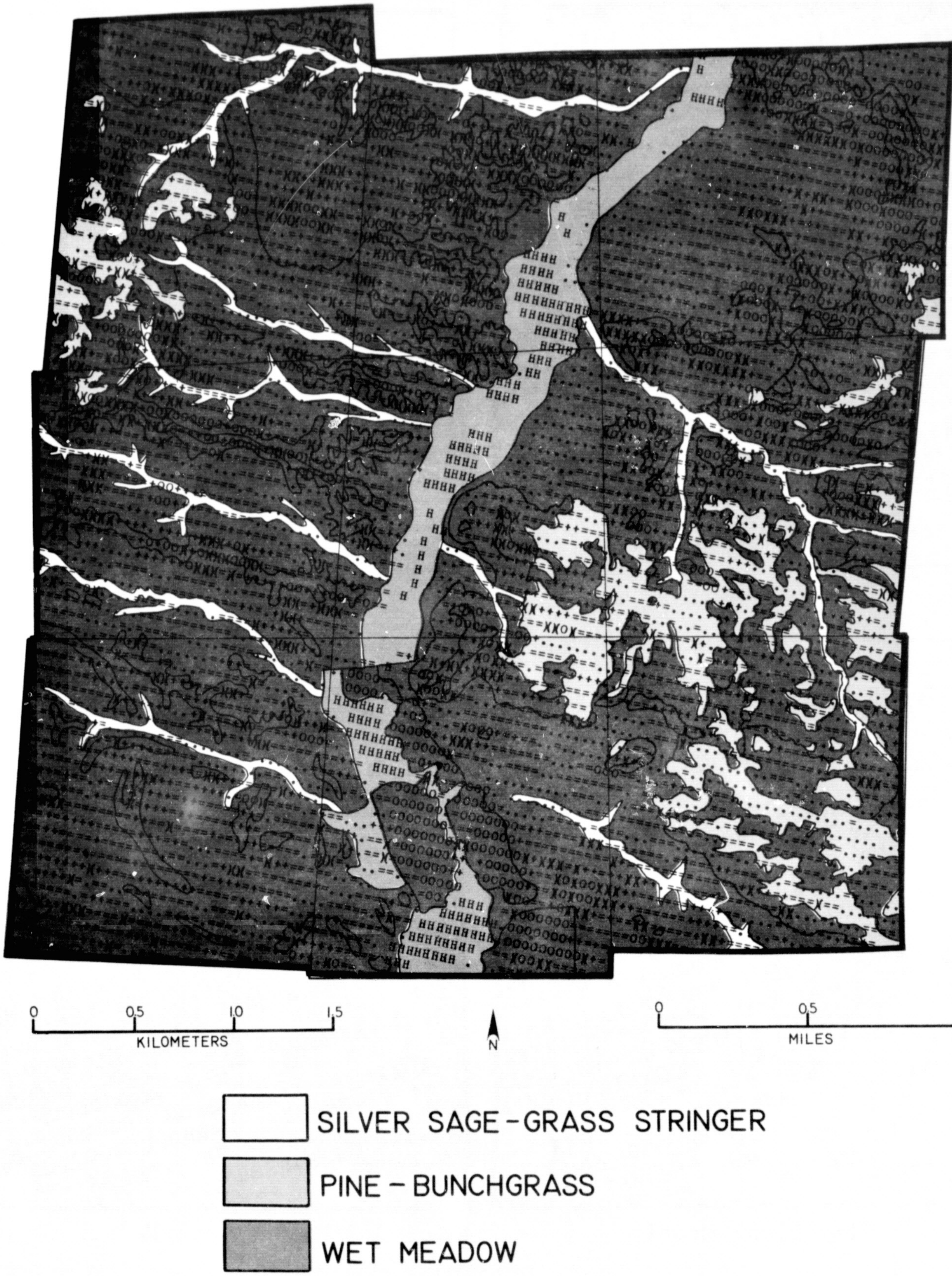
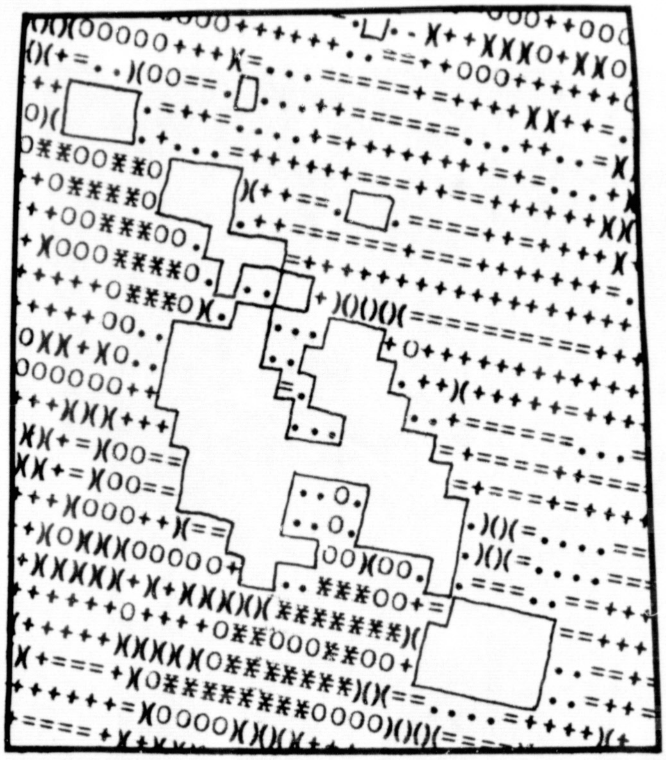
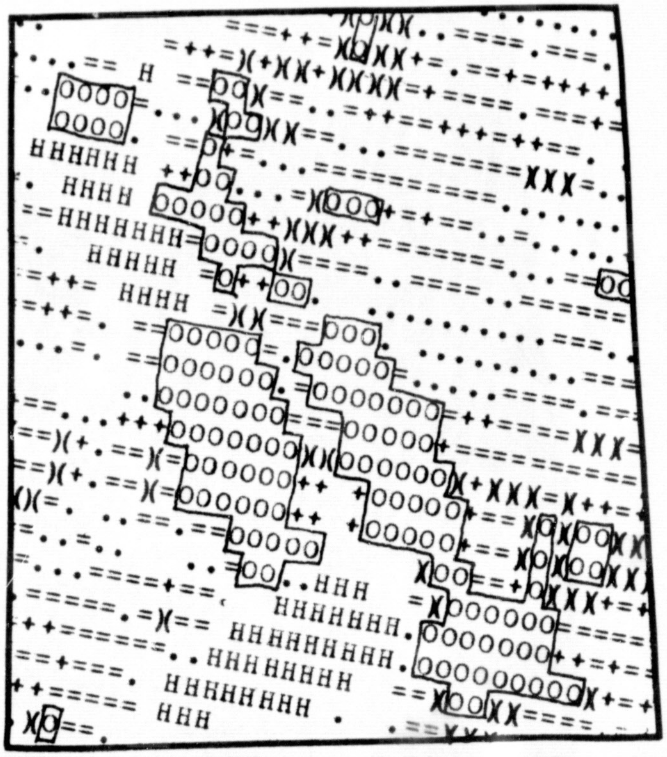


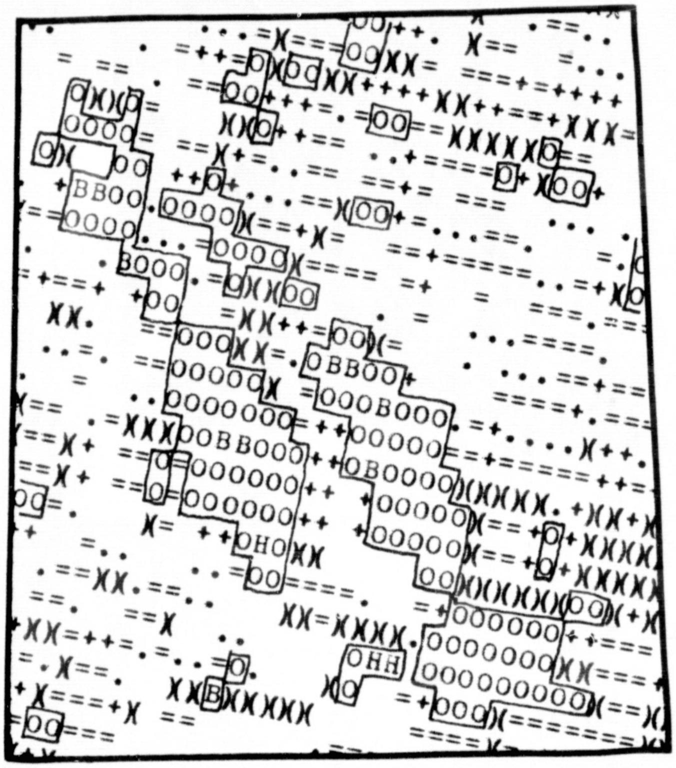
FIGURE 31. $R_{7,5}$ SHOWING WET MEADOW, SILVER SAGE-GRASS STRINGERS, AND PINE-BUNCHGRASS PLANT COMMUNITIES FOR SITE 5, MONTANA.



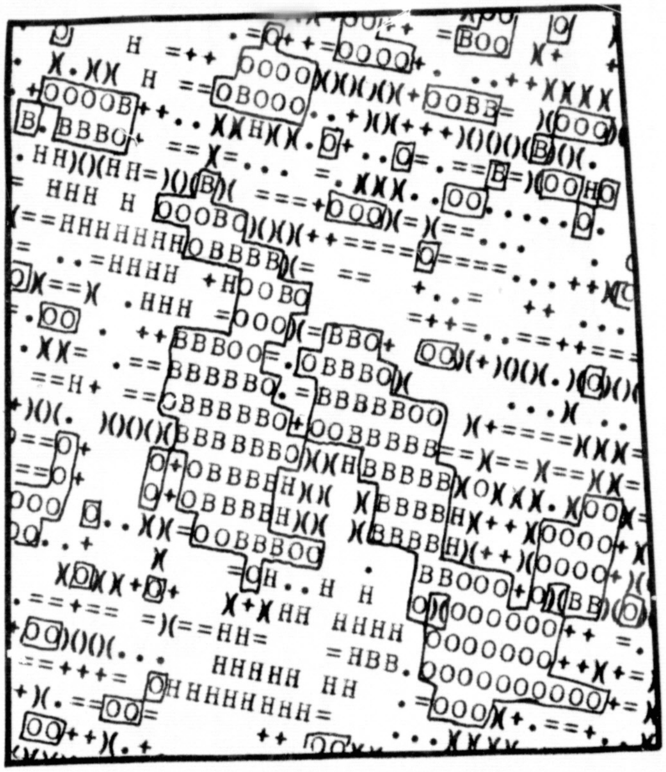
Channel 5



Chan 7/Chan 5 ($R_{7,5}$)



Empirical Model



Theoretical Model

FIGURE 32. FARMLAND IN SITE 5, MONTANA.

and $R_{7,5}$ the densely vegetated cultivated fields (*_*_* in the map of channel 5 and H in $R_{7,5}$) and the freshly plowed completely bare fields (blank in the map of channel 5 and 0 in $R_{7,5}$) are correctly shown. The empirical model, while correctly locating the barest areas, completely missed the planted fields. In fact, it treated the two fields inconsistently, showing one as nearly all blank and the other as nearly all 0. Conversely, the theoretical model not only did a relatively good job of locating the planted fields (denoted by H), the completely bare cultivated fields were assigned values below zero, designated by B on Figure 32. Since the points used for determining the model did not include any with extremely low vegetation cover and the theoretical model has already been shown to be only qualitatively correct, this is not surprising. However, it does show that an additional level of discrimination has been achieved in the theoretical model. These areas are not unique on other LANDSAT products.

In the field, yucca plants make the grass-yucca rolling hills plant community quite distinctive from other plant communities. The grass-yucca rolling hills located in the north of Site 5, however, was unrecognized as different from other grasslands on any of the LANDSAT products. It was even difficult to see the distinction between grass-yucca rolling hills and the adjoining grass flat community on aerial photographs. The reported difference in ground cover for the two different rolling hills grassland communities, 39 percent to 52 percent, may result from an unrepresentative transect. Close examination of the photomosaic at the location of the transect in the yucca-grass rolling hills plant community indicates percent vegetation may have been below average in that locality. The similarity in cover indicated on LANDSAT products may actually be more correct (see Figure 33).

On Site 6 the LANDSAT data did a good job of discriminating greater detail in the rolling hills grassland and sage-grass rolling hills communities. Both channel 5 and the $R_{7,5}$ ratio products provided more information within these communities than had been recorded using the aerial photomosaic. Slightly less densely vegetated ridgetops and more densely vegetated depressions and small drainage channels were separated from the hill slopes and flat areas. After having studied the LANDSAT products, these features can also be recognized on the photomosaic. Initial location of plant community boundaries from aerial photography and field examination did not separate these subtle differences because it was felt that LANDSAT would not be able to classify to such detail and time was not available to complete this more intensive work. MSS channel 5 and the theoretical model for predicting percent vegetation agree that the information collected in the field does not only fail to reflect the overall variability of vegetation cover due to topographic differences, but may not indicate regional differences in the sage-grass rolling hills plant community. In Figures 34 and 35 the three regions of this plant community are annotated as A, B, and C. A and C tend to be lighter in channel 5 (Figure 34) than is B, indicating a greater percent vegetation cover in B. Similarly, A and C in the theoretical model

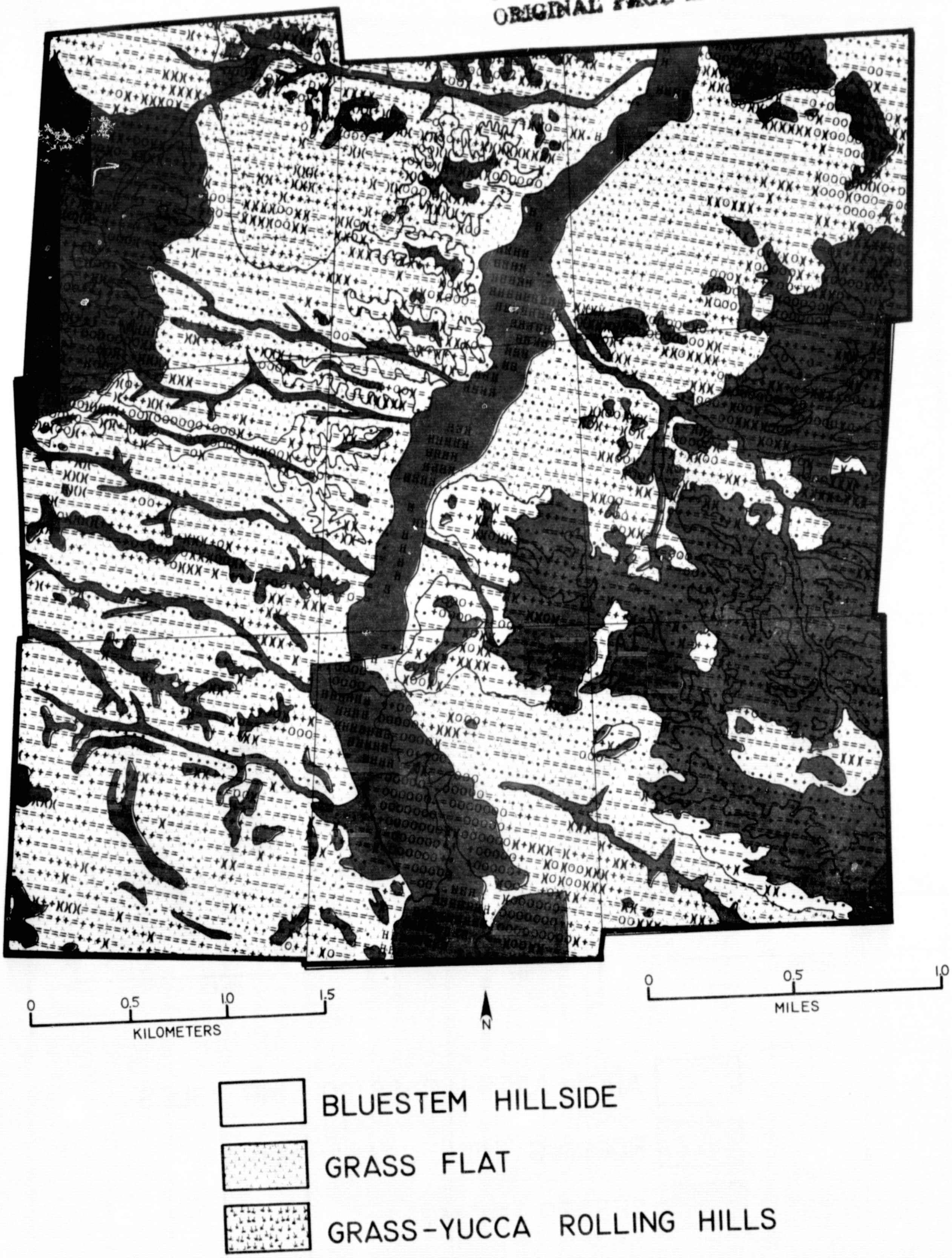


FIGURE 33. $R_{7,5}$ SHOWING GRASS-YUCCA ROLLING HILLS, GRASS FLAT, AND BLUESTEM HILLSIDE PLANT COMMUNITIES FOR SITE 5, MONTANA.

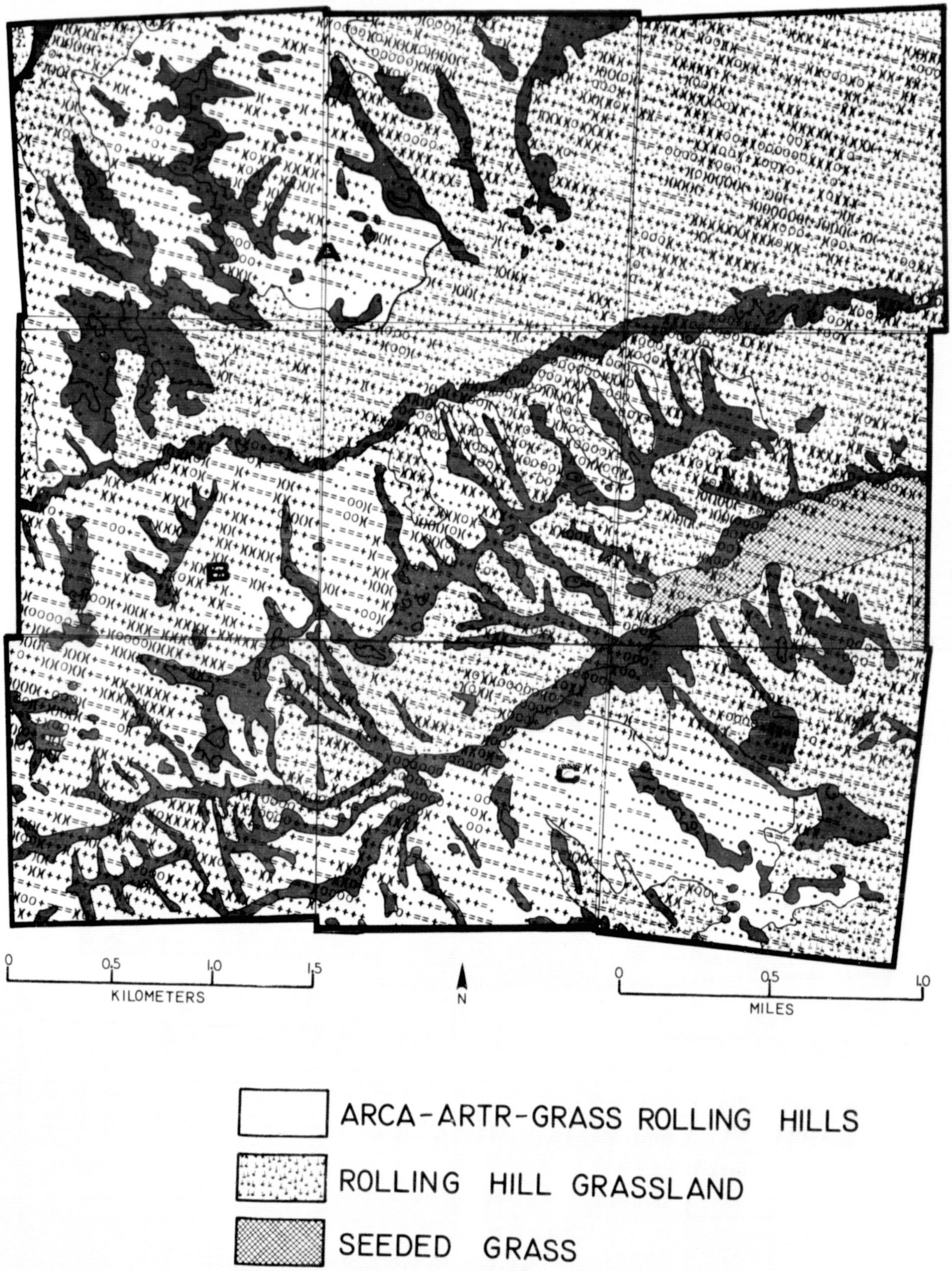


FIGURE 34. MSS CHANNEL 5 SHOWING ARCA-ARTR-GRASS ROLLING HILLS, ROLLING HILL GRASSLAND, AND SEEDED GRASS BOTTOMLAND FOR SITE 6, MONTANA.

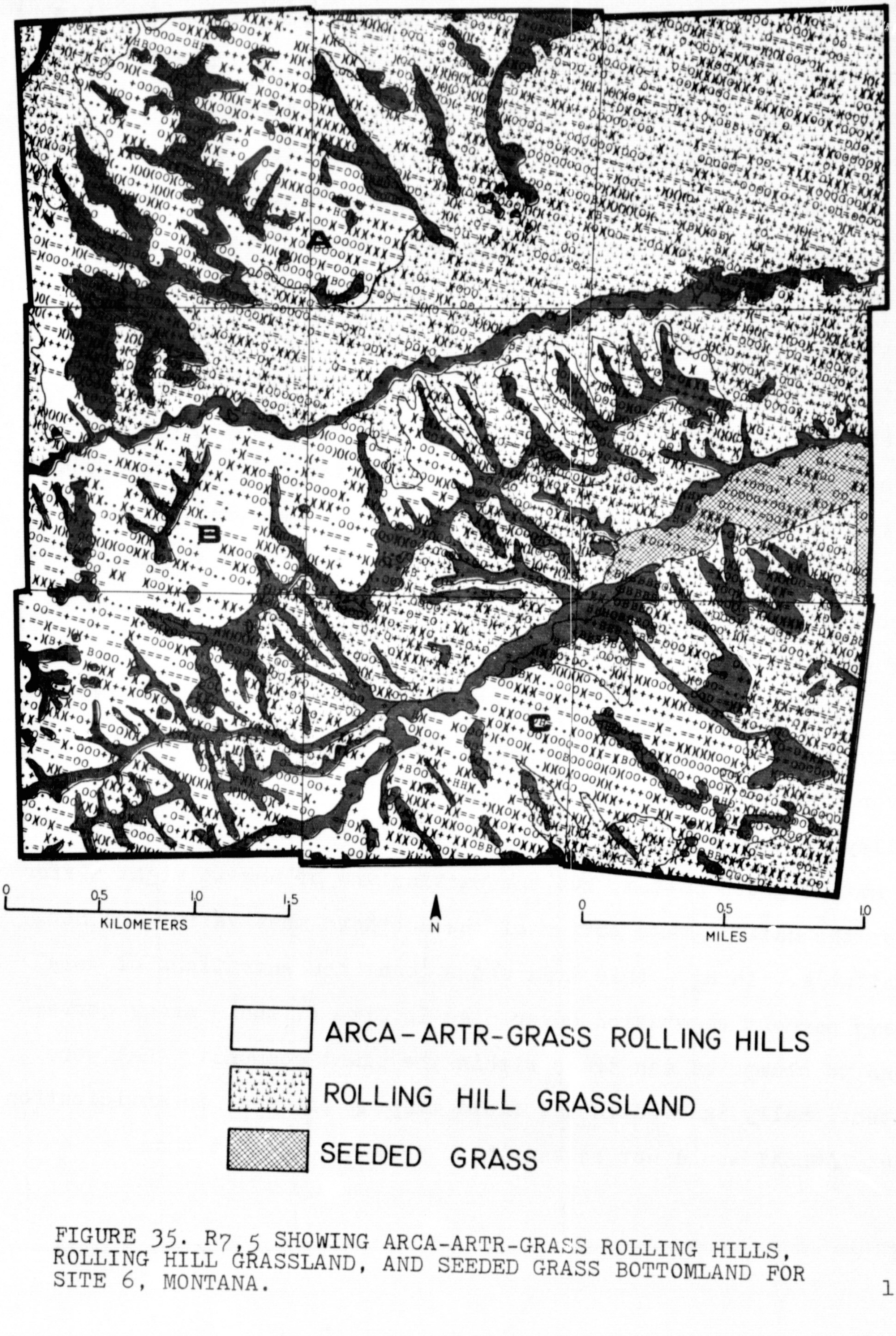


FIGURE 35. R7,5 SHOWING ARCA-ARTR-GRASS ROLLING HILLS, ROLLING HILL GRASSLAND, AND SEEDED GRASS BOTTOMLAND FOR SITE 6, MONTANA.

(Figure 35) are darker than is region B. The vegetation for this plant community was estimated at 52 percent, but LANDSAT data indicates that perhaps it varies among the three regions.

In Site 6 there are two very densely vegetated stream valleys, one vegetated with a silver sage-grass plant community (77 percent ground cover) and the other with native grass (65 percent ground cover). On MSS channel 5 (Figure 36) these two major valleys are easily seen, but no difference in the two is shown. We suspect that although the silver sage-grass bottom is more heavily vegetated, the reduced chlorophyll absorption of the sage shrubs makes this plant community a little higher in reflectivity, corresponding in MSS channel 5 to reduced vegetation cover. Literally none of the area appears as dark in channel 5 as the alfalfa fields (70 percent vegetation cover) appeared in channel 5 of Site 4 (see Figure 22).

In contrast, $R_{7,5}$ (Figure 37) was able to correctly show the native grass bottom drainage to be lower in percent vegetation cover than the silver sage-grass bottom found in the southern-most valley. The east end of the south valley was mapped in the field as native grass bottom, but the particulars of how it might differ from the native grass bottom of the northern-most valley are not available. In $R_{7,5}$ this area shows local concentrations of very heavy percent vegetation cover. As in Site 5, these areas correspond to clumps of ash trees within the plant community that were intentionally ignored in the field mapping process in anticipation that LANDSAT would not be sensitive enough to detect them.

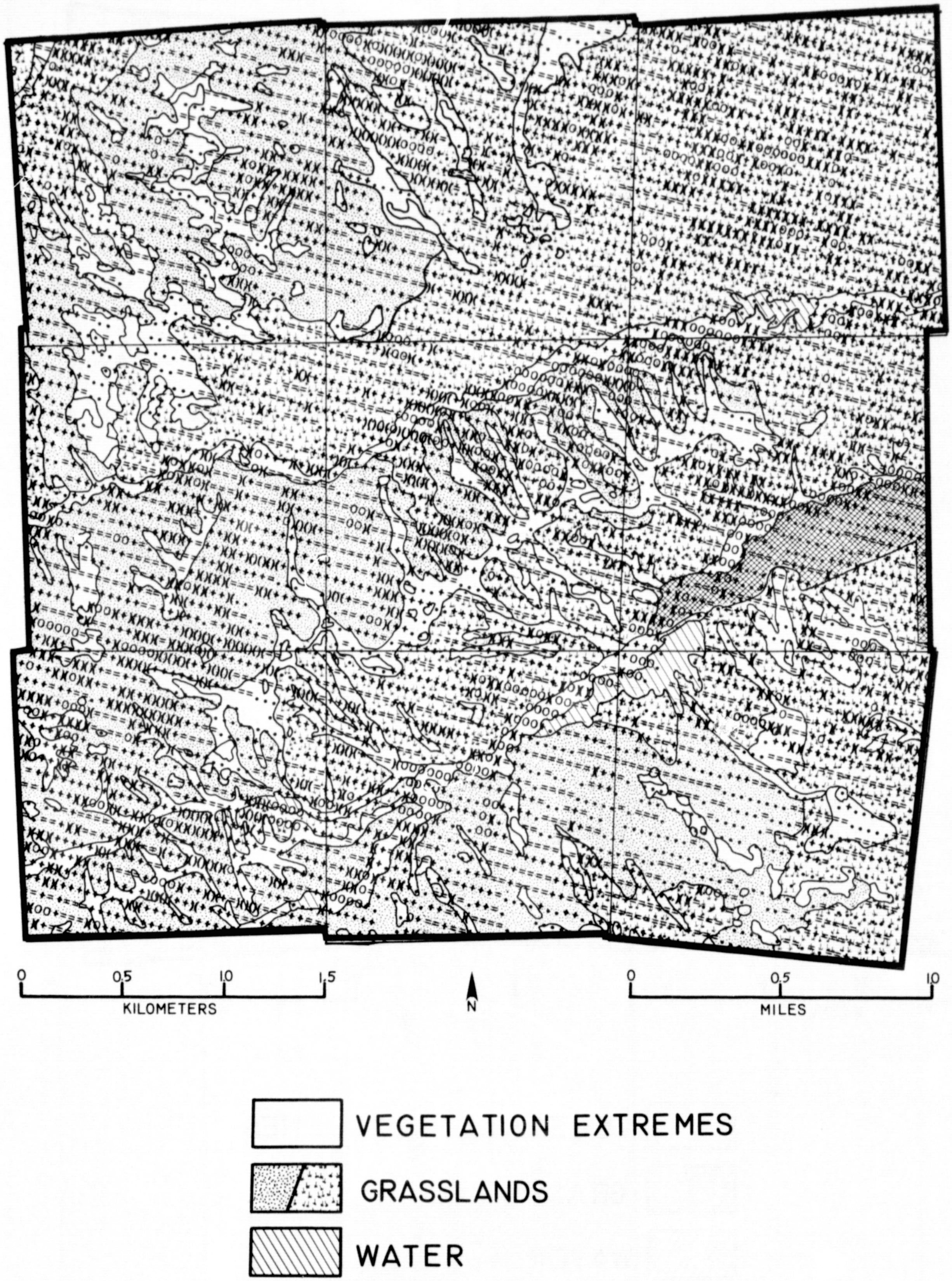


FIGURE 36. MSS CHANNEL 5 SHOWING PLANT COMMUNITIES WITH VEGETATION EXTREMES FOR SITE 6, MONTANA.

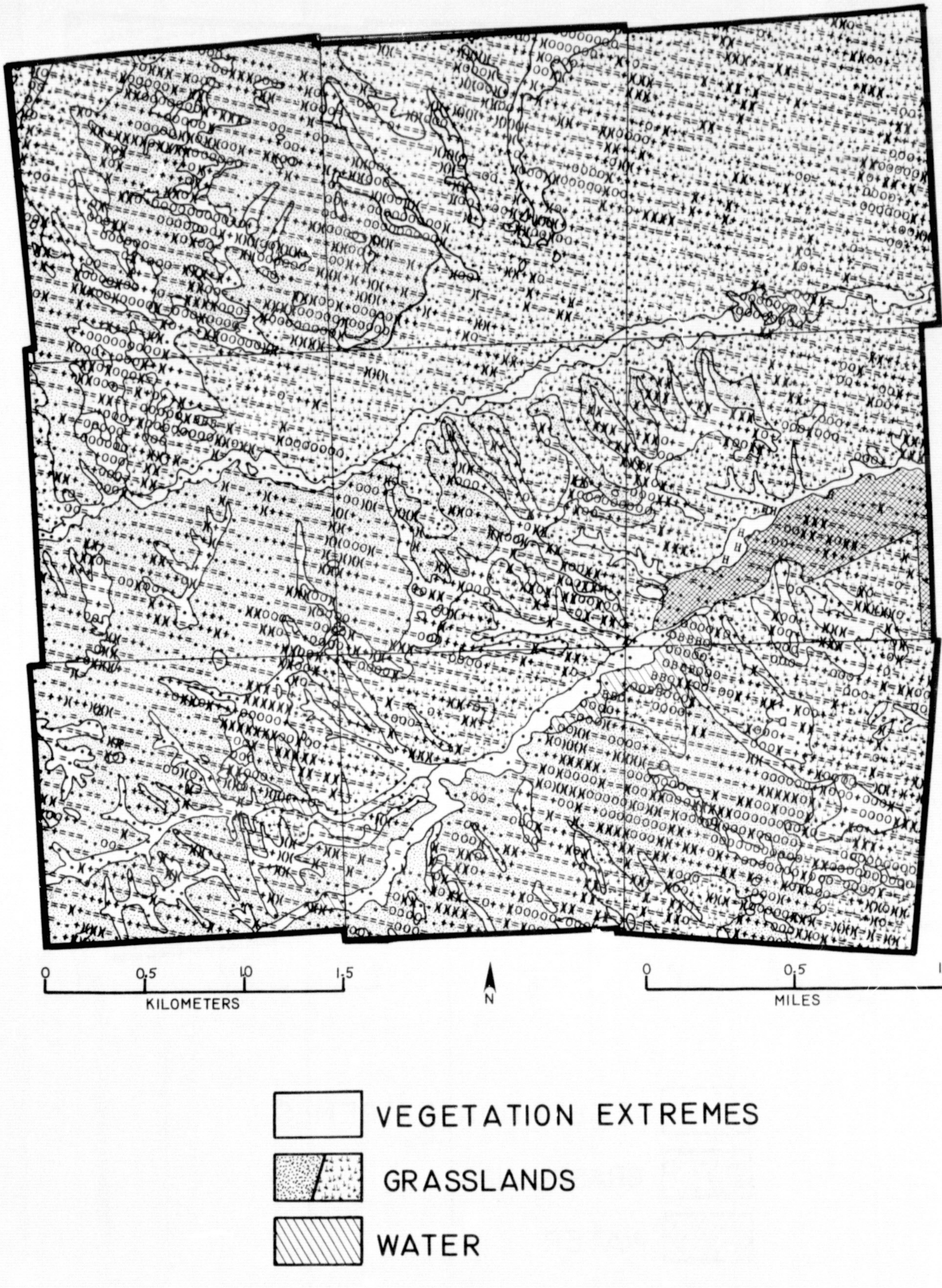


FIGURE 37. $R_{7,5}$ SHOWING PLANT COMMUNITIES WITH VEGETATION EXTREMES FOR SITE 6, MONTANA.

Reevaluation of those areas which had been mapped as ridgetops and barren hillsides showed that most of the LANDSAT products were again accurate in their placement. However, silt-laden, muddy water in several large reservoirs looked identical to barren hillsides in channel 5(Figure 36). On the ratio products (Figure 37) the water was more often shown as zero vegetation cover, as were the cultivated fields in the theoretical model application to Site 5. Comparison of the products with the photomosaic showed that the field map and MSS channel 5 were influenced in their recognition of barren hillsides by albedo differences in the underlying rocks and soils. Ratio products were less influenced by outcrops of white rock, and showed more area of sparse cover which, upon reconsideration, was more representative of the area.

5.3 Summary

Nearly all physical features which could be seen on the aerial photomosaics could also be identified on LANDSAT data. This included topography, percent ground covered by vegetation, and in some cases the amount of green versus dry plant material. In some cases visible plant characteristics were not seen, such as pine trees, yucca plants and silver sage shrubs not being classified on LANDSAT data. It appears then that LANDSAT data is much more sensitive to variations in percent of ground covered by live vegetation than to differences in plant species.

In Arizona, the desert perennials were difficult to identify where vegetation is so sparse that sufficient contrast is not afforded in the LANDSAT data. However, plant community boundaries are somewhat correlated with soil types, topography, exposure, etc. These characteristics are more visible on LANDSAT data than those of plants in the ephemeral rangeland.

One of the greatest difficulties in comparing LANDSAT data for Montana with ground verification information resulted from problems created by aerial photo distortion and lack of sufficient transect data. Aerial photomosaics were badly distorted because of parallax resulting from poor photograph-to-ground angle control. This is evident in the difficulty of matching photographs when producing a mosaic.

Very accurate location of sites on LANDSAT data was difficult because of a lack of good control points. This is a function of the relatively small size of test sites used and stretching of satellite data to its maximum scale (1:18,000). The large scale was very useful in mapping vegetation and soil parameters. It is apparent that LANDSAT data is capable of classifying to a greater detail than originally anticipated. The lack of equally detailed ground data did not permit analysis of the accuracy or of factors which contributed to the resulting errors. The ability to expand LANDSAT data to a very large scale is of potentially great benefit to managers of natural resources.

The relatively constant scale of LANDSAT imagery is helpful when transferring resource information to standard maps. Experience has shown that error in standard Sioux Falls paper prints is within error limits of plant community boundaries drawn on satellite imagery. It is not anticipated that increasing scale of products will increase geographic distortion beyond acceptable limits.

The ability of computer-processed LANDSAT data to help map and classify vegetation and soils in a variety of useful formats is extremely important. As in this study, terrain features often influence the mapping and classification of plant communities in the field.

Some plant communities are separated according to topography when steep hillsides, ridgetops, low rolling hills, valleys and drainage bottoms result in variation in plant composition and density. In this study channel 5 classified vegetation and topography together, recognizing plant communities influenced by important terrain characteristics such as slope and depth of soil. These factors affect grazing patterns and availability of forage for livestock. In range management, the effects of topography on livestock grazing patterns are important. Cattle tend to concentrate grazing on flat, rock-free valleys, leaving steep hillsides alone until feed becomes short on more favorable areas. Shallow soils on steep slopes or ridgetops may also produce less forage than do the more accessible valleys. These factors bring up an important consideration for future plans for LANDSAT multispectral processing. In some BLM applications, use of single channel data for recognition of terrain differences may be as important as the signature extension and enhancement of spectral features allowed in ratio products.

The $R_{7,5}$ product and, to a greater extent, the predictive models gave percent of ground covered by vegetation independently of topography. Plant communities such as the upland grass and bluestem hillsides of Site 4, as they were mapped in the field, had very similar percent vegetation cover. The ratio products tended to show this similarity, as well as the changes in percent cover within the plant communities. Such products could be important for preparing forage potential maps, independent of the influence of topography. Sequential $R_{7,5}$ or predictive models maps could also provide information on changes in ground cover which result from grazing. Such changes would be used to determine trends in range conditions.

Total plant production data, the current seasons growth by plant community, was collected for sites in Montana. This data helps to explain why some differences in plant communities can be distinctly separated and others cannot on LANDSAT data. Densely vegetated communities found along valley bottoms can be separated from barren hillsides and upland grass areas. Plant production data in Table 18 show a 4 to 10 fold difference in production between valley bottoms and barren hillsides, and a 2 to 3 fold difference between valley bottoms and upland grass areas. However, differences between all upland communities (upland grass, bluestem hillside, sage-grass upland, ridgetop, and pine-bunchgrass) are slight--10 to 50 percent. Upland communities were difficult to separate on LANDSAT data.

TABLE 18. TOTAL PLANT PRODUCTION (CURRENT SEASON'S GROWTH BY PLANT COMMUNITY FOR THE THREE TEST SITES IN MONTANA).

Liscom, Site 1 7-28-75	1975 Plant Production (Air dry wt. - kg/ha)
Upland grass	1715
Bluestem hillside	1547
Barren hillside	605
Ridgetop	1592
Pine-bunchgrass	1166
Grass-dandelion bottom	2712
Allen, Site 2 7-29-75	
Sage-grass upland	1087
Grass flat	3038
Bluestem hillside	1872
Ridgetop	1558
Pine-bunchgrass	1670
Wet meadow	6624
Scott, Site 3 7-30-75	
Rolling hill grassland	3183
Arca-Artr-Grass rolling hills	2208
Barren hillside	516
Ridgetop	1267
Silver sage-grass bottom	4125
Seeded grass bottomland	4181

1 pound (lb) = .453592 kilograms (kg)
1 acre (a) = .40468564 hectares (ha)

1 lb/a = 1.12085 kg/ha

Plant production for several communities does not correlate directly with the percent of ground covered by live vegetation. For example, the sage-grass upland community produced three times less plant material than the grass flat community on the Allen Ranch (Site 5), even though both communities had similar densities. On the Scott Ranch (Site 6), the silver sage-grass and seeded grass communities, both valley bottom areas produced the same amount of plant material, but the seeded grass community had only slightly more than half as much ground cover as found in the silver sage-grass community. These findings are in agreement with results of studies where big sagebrush has been converted to grass. The somewhat higher production for the ridgetop community on the Liscom Creek (Site 4) when compared to communities on deeper soils, such as the bluestem community with greater percent ground cover, is probably the result of the small size (one clipped plot per plant community).

Plant communities with similar percent ground cover are very difficult to separate on all the products. For example, lower density pine-bunchgrass stands are confused with upland grass communities and silver sage-grass communities are also confused with upland grass. It is evident that more variability exists in percent ground cover of plant communities than was thought to exist at the beginning of the study. Also the LANDSAT data seems to be better able to distinguish differences in percent ground cover than between species of plants, although some species can be anticipated to have measurable effects when simple relationships exist. In addition, some of the differences in percent ground cover shown on LANDSAT data may not be real. There may be also a reflection of the amount of green versus dry plant material existing on the area. A high percent of green in grasses may have been interpreted as a higher than normal percent ground cover.

6.0 AUTOMATIC RECOGNITION PRODUCT RESULTS

6.1 Maximum Likelihood Classification in Arizona

The maximum likelihood classification map of Site 1 in Arizona compares well with the MSS channel 5 product resulting from level slicing (Figures 14 and 38). General topographic features and soil types known to exist on the site are visible on both products. Classification appears to have been influenced by the combined signatures of soil and vegetation as well as the presence of shadows. The maximum likelihood recognition map appears to contain some additional information and slightly greater detail within plant communities; whether this is actually increased resolution or just a function of the number of recognition classes used is an unresolved question.

Three distinct zones of vegetation and soils have been visually separated in Site 1, moving west to east. The first area is composed of rolling hills, gravelly sandy loam soil, and a relatively dense (16 percent ground cover) mixture of desert trees and shrubs. This area was chiefly mapped as Plant Community 6 on the field map and shows up in the automatic recognition as principally light green (Figure 38). Local differences in slope, depth of soil, and concentration of trees in ephemeral washes (where runoff collects following thunderstorms) are shown as a variety of colors representing a conglomeration of recognition classes within the rolling hills region.

Another area of rolling hills, considered to be part of this first general vegetation zone, is located in the southern corner of the site, shown mostly as purple in the recognition map. This area, Plant Community 13, is similar to Plant Community 6 with relatively dense vegetation, yet it appears quite distinct on all LANDSAT products. In the field the soils, rock content, and plant characteristics did not appear unusual in this region. The unique appearance on LANDSAT data must stem from the influence of nearby geologic formations. The materials underlying this plant community are directly derived from Precambrian metamorphic rocks which outcrop just south and outside of the test site.

The second and central zone evident on the recognition product is made up of two outwash plains with a sandy loam soil and moderately dense vegetation (6 to 9 percent ground cover). On the field map, this zone can be generally characterized as plant communities 2, 4, and 5. The two outwash plains are separated by a broad, sandy wash.

The third zone of vegetation recognizable on the classification map is the eastern corner of the site, characterized as relatively flat with sandy soil and sparse vegetation (3 to 6 percent ground cover). Plant communities 3, 7, 9, and 10 can be included in this group, although Plant Community 9 is somewhat distinctive from the other three. This area is bisected by several wide, sandy washes, the outlines of which are faintly visible on all LANDSAT products. The general outline of the major ephemeral drainage channel leading from these washes and running south-southwest can be seen more distinctly on the maximum likelihood

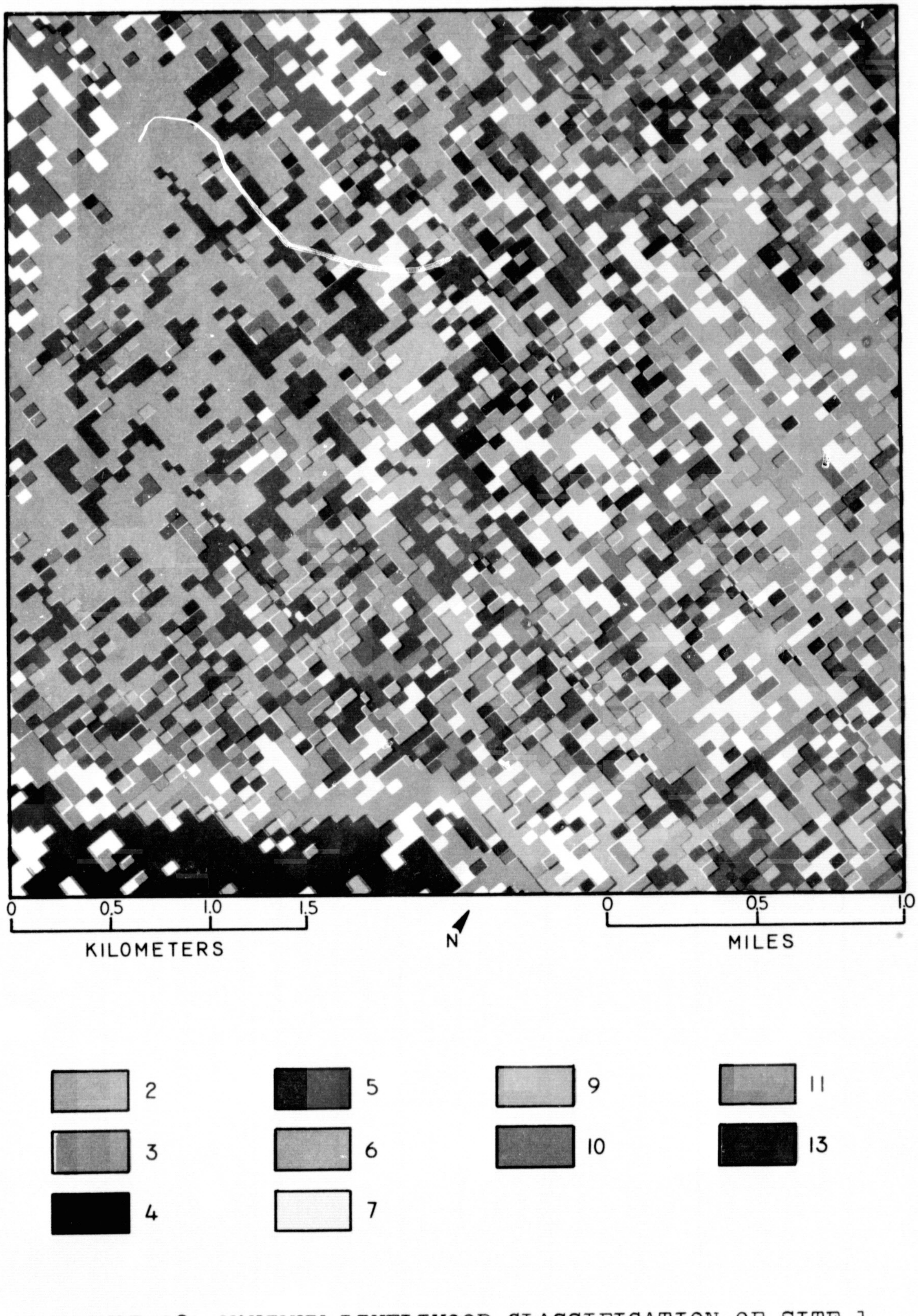


FIGURE 38. MAXIMUM LIKELIHOOD CLASSIFICATION OF SITE 1, ARIZONA.

classification than on MSS channel 5.

6.2 Ratio Gating Logic in Montana

The ratio gating logic recognition map of Site 4 (see Figure 39) only did a good job at classifying the obvious plant communities, i.e. alfalfa fields, grass-dandelion bottom, and barren hillsides. The other recognition, although locally satisfactory, was not consistently good across the scene. Some recognition was notably bad, as in the case of the silver sage-grass community located in the Liscom Creek valley. In the ratio gating product, almost no accurate recognition of this community occurs other than a few of the original target pixels. Instead, isolated recognition (green in Figure 39) crops up all around the site, chiefly in upland grass plant community localities. Conversely, most of the silver sage-grass bottom locality was classed as upland grass by the automatic recognition. Recognition of bluestem hillsides was similarly diffuse and inaccurate. The use of ratios as spectral parameters seemingly did reduce the effects of topography on which the definition of bluestem hillside and upland grass areas was originally dependent.

Figure 40 shows the relationship of ranges of signatures used for the eight plant communities of the Liscom site. Four of the ratios ($R_{6,4}$, $R_{6,5}$, $R_{7,4}$, and $R_{7,5}$) seem to give similar information about the plant communities. $R_{5,4}$ and $R_{7,6}$ signature relationships are substantially different from the others

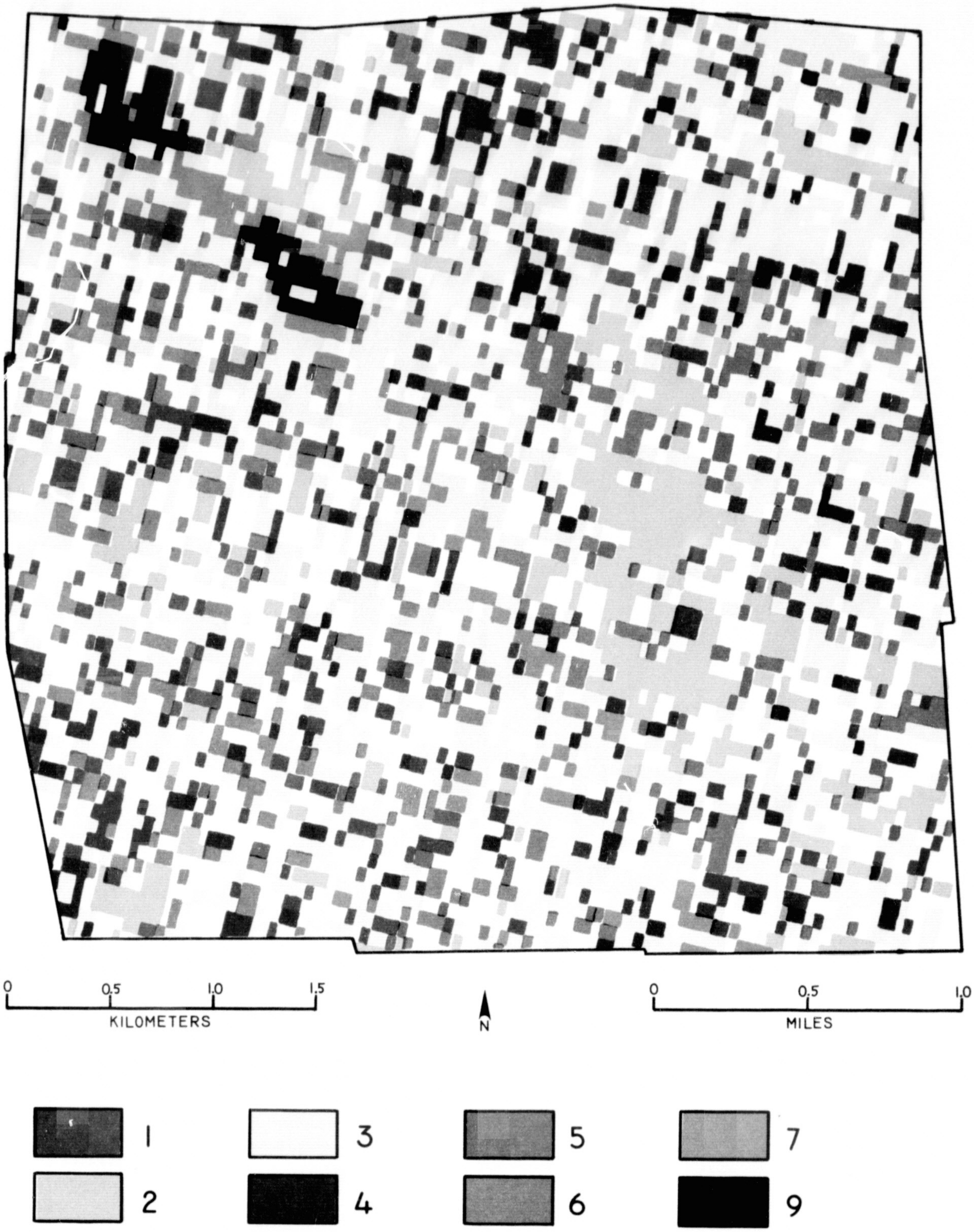


FIGURE 39. RATIO GATING LOGIC AUTORECOGNITION OF SITE 4, MONTANA.

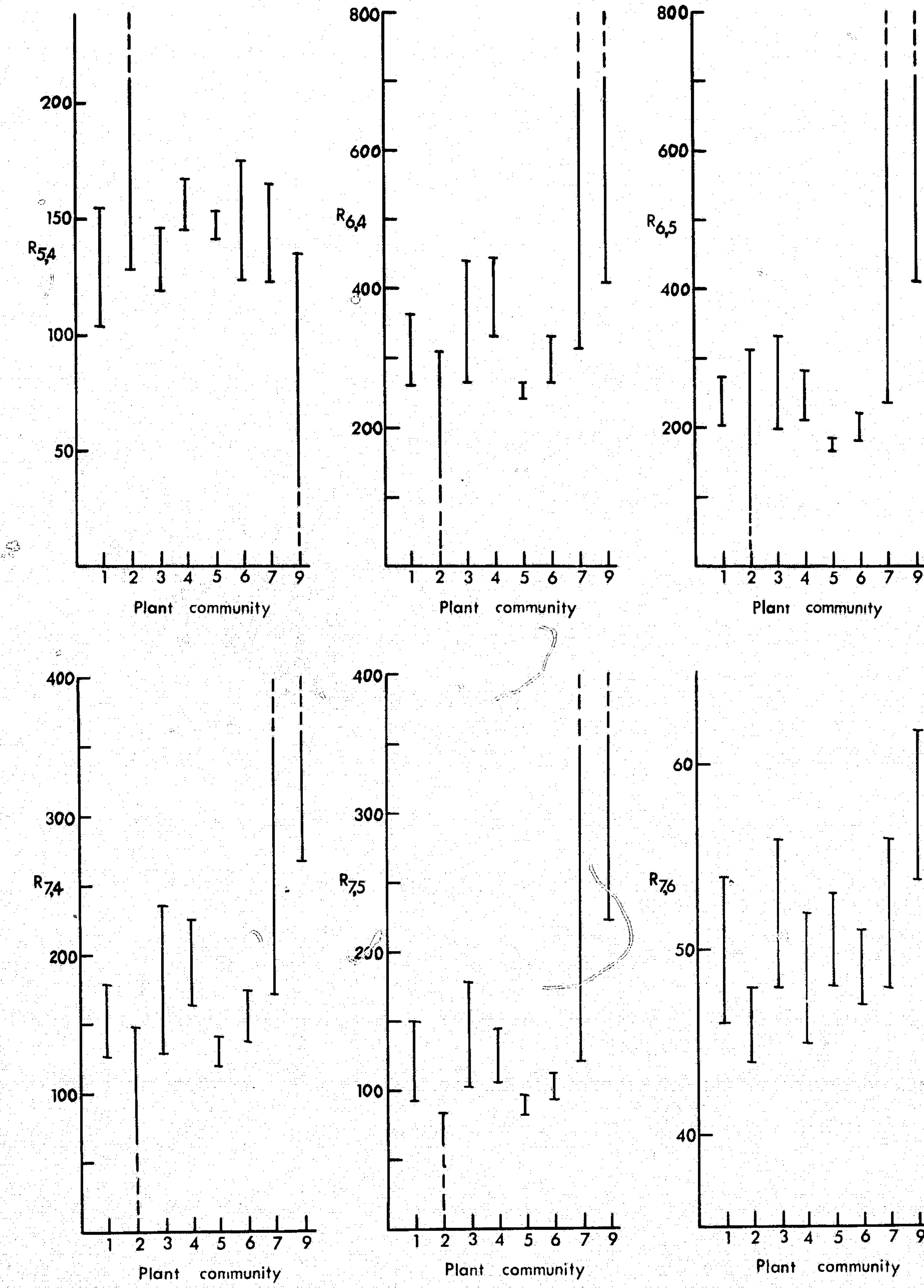


FIGURE 40. MONTANA SITE 4 PLANT COMMUNITY SIGNATURES FOR LANDSAT SPECTRAL RATIOS, DATE 5 (JUNE 23, 1975).

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and from each other. $R_{7,6}$, however, shows a great deal of variation in each signature, resulting in extensive overlap. For this reason, this ratio was not used in automatic recognition.

Nesting and overlap does occur between other targets also. Little could be done to improve the recognition achieved here for the eight plant communities designated. Even an increase in overall percent classification from the present 72 percent was not possible through uniform target expansion without obvious downgrading of the targets which occur late in the decision string.

6.3 Maximum Likelihood Classification in Montana

The maximum likelihood classification of Site 4 in Montana on single channels of LANDSAT data conforms closely with the prior results obtained with ratio gating classification (Figures 39 and 41). It appears that where ratio gating was able to recognize a plant community, maximum likelihood could also classify that community, but usually with greater accuracy. Where ratio gating was unable to distinguish between plant communities with similar percent ground cover, maximum likelihood also had difficulty making accurate recognition. Few inconsistencies were found in the results of the two classification techniques, but maximum likelihood could classify several plant communities which were not recognized well on the ratio gating recognition map.

As in the other LANDSAT products, alfalfa fields and barren hillsides were unmistakeable on the maximum likelihood classifica-

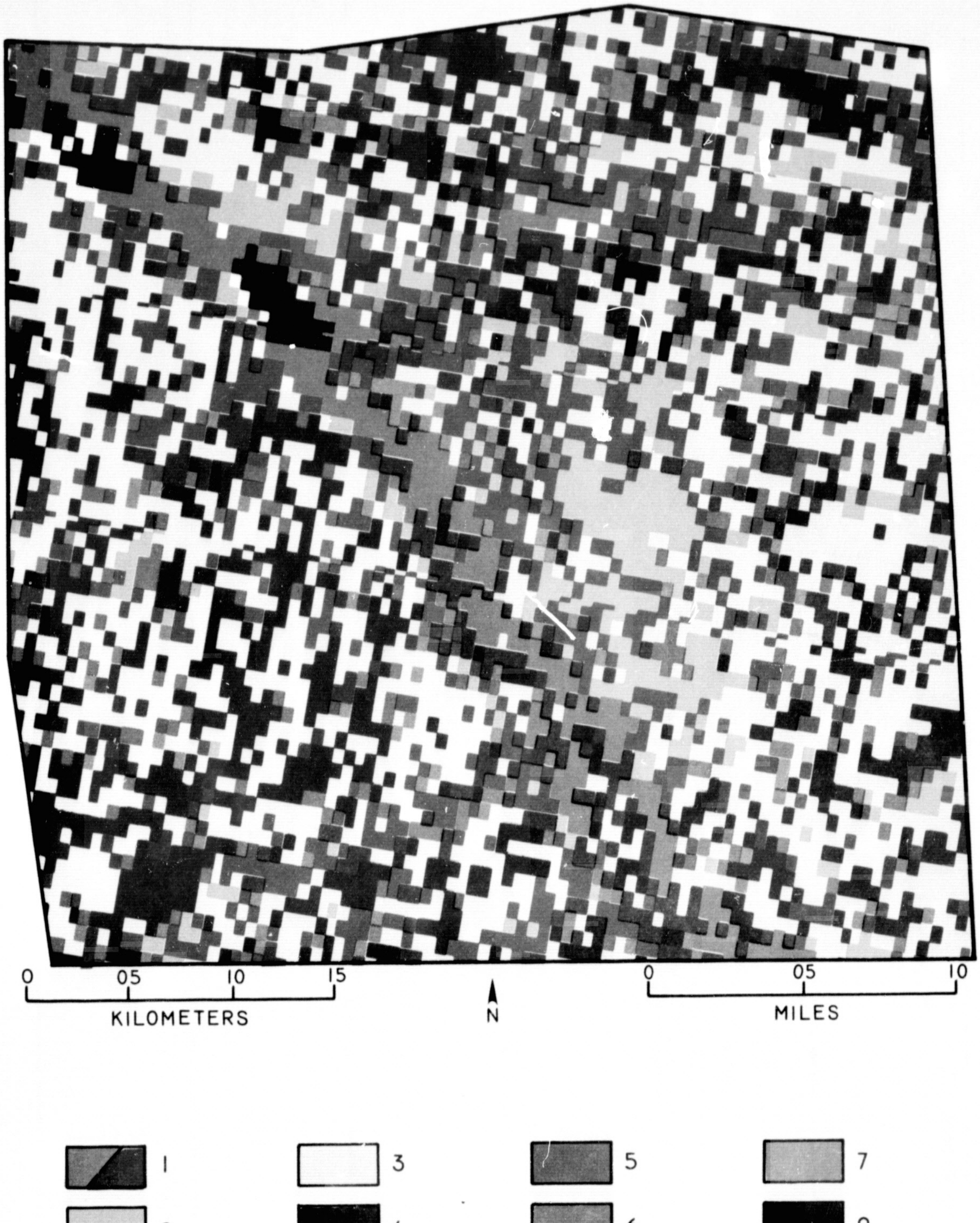

FIGURE 41. MAXIMUM LIKELIHOOD CLASSIFICATION OF PLANT COMMUNITIES IN SITE 4, MONTANA.

tion (see brown and gray on Figure 41). Recognition of ridgetop sites, shown in red, was considerably improved over the previous recognition effort. Nearly all of those areas classed as such are done so correctly. One notable exception is a stringer of red recognition following the southwest border of the bottomland of Liscom Creek. Although not ridgetop, this recognition has correctly defined a good-sized road that was not depicted on the field map, but which is probably more correctly classed with ridgetops than with the silver sage-grass bottom in which it had been included.

On the other hand, not all the ridgetop that had been mapped during field work has been mapped as such in the maximum likelihood classification. Where ground cover on ridgetops is likely to have actually been greater than the prescribed 32 percent, in this product it is often classed with the upland grass areas or some other, more densely vegetated community.

The pine-bunchgrass community was properly classified wherever it occurred within the site. Some additional areas of other communities have been mistakenly included as pine-bunchgrass also. Close analysis of aerial photographs reveals that the broad pine-bunchgrass community is actually made up of stands of widely varying tree densities. No attempt was made to separate pine stands into communities of like density. The maximum likelihood product showed pine-bunchgrass areas properly, independently of density of pine. However, ash trees along Liscom Creek were also classified with the pine-bunchgrass community.

Where bluestem hillsides were recognized, they were placed correctly. However, the number of pixels included as this plant community was small. Much of this community was improperly classified as upland grass or pine-bunchgrass. This is likely to be a result of their similar percent ground cover. On occasion, pixels identified as bluestem hillside fall within pine-bunchgrass areas.

The areas classified as upland grass generally coincide with areas designated as upland grass on the field data. However, not all of the upland grass areas were classified as such. As described earlier, ridgetops with a higher than average density were improperly classified as upland grass. The depressions and valleys where grass plants are most dense were improperly classified as the pine-bunchgrass community. In addition, where vegetation was particularly dense in the upland grass sites, areas were recognized as more similar to plant communities with higher prescribed percent vegetation, such as the grass-dandelion bottom or silver sage-grass bottom.

The larger areas of the grass-dandelion plant community occurring in the bottom lands along Liscom Creek were properly classified using the maximum likelihood technique. The grass-dandelion community occurring along narrow ephemeral stream channels (shown as orange in Figure 41) was only sparsely recognized. Most often, recognition of this rather densely vegetated plant community only occurred where the valleys widened somewhat, allowing whole pixels to fall over the area. This was thought to be a negative result which was probably due to inadequate spatial resolution. The spectral signature seemed adequate, as recognition was restricted solely to drainage channels where the grass-dandelion community is located.

The silver sage-grass community was poorly recognized because of confusion with the upland grass and grass-dandelion bottom communities. The ephemeral streams are visually outlined on the recognition map primarily because of misclassification of these areas as silver sage-grass. The confusion exists because of the similarity of percent ground cover for all three communities and although silver sage is very evident to the observer, when sparsely distributed it does not influence LANDSAT data sufficiently.

6.4 Summary

No quantitative measures of accuracy of recognition are being reported. The automatic recognition procedures which were finally achieved in the study are somewhat different than those which had been included in the original architecture. Our qualitative discussion of the results is probably less misleading than a method of calculating accuracies designed after the results had been evaluated subjectively. Quantitative comparison of the two automatic recognition products is also not straight forward. They contain different numbers and distributions of pixels due to the application of different geometric corrections.

Usually such reports contain summations of recognition, or confusion matrices, or some like measure of accuracy. The results of the automatic recognition performed for this study can be summarized as the following:

1. Ratio gating logic applied to five ratios in perennial rangeland resulted in 72 percent classification of the scene with accuracies which are not thought to be applicable in an operational system.
2. Maximum likelihood classification applied to four MSS channels for perennial rangeland resulted in 99 percent recognition and the accuracy achieved shows possible operational uses.
3. Maximum likelihood classification applied to three single channels of data in ephemeral rangeland showed little improvement over detail that could be seen in a density-sliced single channel.

Other automatic recognition procedures were not applied but may be found to be more useful in some plant community recognition. We do report some limited recognition of the influence of plant species on LANDSAT signatures. However, our research indicates that whatever the decision rules applied, the spectral configuration of LANDSAT seems more sensitive to differences in vigorous vegetation than to actual physical and spectral differences among plant species.

7.0 RECOMMENDATIONS

7.1 LANDSAT Multispectral Data

1. BLM should develop an in-house capability to process and use LANDSAT multispectral scanner data, both imagery and computer-compatible tapes (CCT's).

This will enable BLM to develop the future capability of fully utilizing data with the increased spectral and spatial (30 meter) resolution projected by NASA for LANDSAT-D, when it becomes available.

7.2 Field Method for Plant Community Data

A standard BLM field technique, such as the toe-pace transect, normally used to gather rangeland resource data can be used to gather ground data to accompany LANDSAT data. However, some minor adjustments are needed. These include measurement of aerial grass parts and placement of a representative number of transects in each plant community encountered. Guidelines for adjustment of this procedure should be formulated with both consideration of satellite data configuration and requirements for other uses of the data that must be collected while in the field.

7.3 Field Spectrometer Measurements

Theoretical results and predictive models are subject to more and different degrees of freedom than are empirical results. Theoretical models must be scaled to LANDSAT data using a normalization coefficient, $K_{i,j}$, calculated for each spectral parameter. As was the case for final products in this study, the quantitative value of theoretical results can be seriously altered by inaccurate determination of these coefficients. Also, field spectrometer measurements must be sufficient in number and quality to provide accurate values for generating theoretical LANDSAT data for rangeland plants and soils.

We recommend that a library of field spectra of soils and plants be initiated, expanding upon those collected for this project, and that the simple model for plant community spectra be continued, incorporating the greening curves of plant species. This project proved at least the qualitative use of the theoretical plant community spectra. In its final form, the theoretical method could be quite useful for selecting multispectral and multitemporal data processing algorithms.

7.4 Theoretical Approach

Since ratio normalization can be done with little field information when only a few points are known extremely well, the theoretical procedures could result in cost savings when perfected. We propose that control areas could be identified for use in calculating $K_{i,j}$. These areas should be fairly uniform throughout a rather large area, having relatively low topographic relief, and be easily accessible to BLM personnel. We suggest that an area approximately 790 meters x 790 meters (10 x 10 LANDSAT pixels) be a minimum size for a control site. BLM personnel could then keep a record of the information important to LANDSAT studies and occasionally take field spectrometer measurements on these sites. This would allow calibration of other spectral work to be done in that area.

Calibration of data sets to a known reflectance value does not improve discrimination among targets within a single data set. It is merely a technique for relating the range of values of theoretical data sets to correlative LANDSAT data in an absolute sense, or for extending recognition results in time and space. Sites located in areas where LANDSAT frames overlap side-to-side, can provide additional information useful for signature extension.

7.5 Automatic Recognition

Supervised training techniques still have some major problems which reduce their usefulness in operational applications. The accurate location of target areas where plant communities are small, along with spatial resolution, remains a tedious, unpredictable approach. The requirement for large numbers of pixels for statistical classifications, such as the maximum likelihood decision rule on target signatures, will not be easy to fulfill in some natural environments. The gradual change often found from one plant community to another (ecotone) can be somewhat difficult to handle in supervised classification methods. Unless the same number of pixels is sampled for each plant community, the relative variability within any spectral parameter is not adequately specified and could be misleading.

Ratio gating logic, or other binary sequential decision rules, also have some disadvantages for an operational system when compared to statistical decision rules, although they usually do have some financial advantages. The foremost disadvantage, although on a limited basis this feature can be used to advantage, is the target-order dependency of the results. Not only can the results vary widely with changes in ordering of the same targets, a target early in the decision string may artificially be enriched at the expense of later, legitimate targets. A second disadvantage of binary sequential logic is the inability to increase overall recognition by other than arbitrary methods. In an operational system a trade-off must be made between precise accurate recognition, although sparse, and additional recognition at a specified, possibly reduced probability of accuracy.

The recognition of plant communities in natural environments is somewhat different than agricultural recognition where, for a field of a certain size, one can assume a certain discrete, homogeniety of target. The requirements are also more stringent than in land use applications of LANDSAT data. In such cases, percent vigorous vegetation can often be correlated with substantially different cover types, such as impervious surfaces, zero percent vegetation, with "dense urban", and densely vegetated (trees) suburban, with "old residential". Species differences within rangeland important to grazing conditions may be crucial in the resource inventory. If resource managers need plant community classifications which are beyond the spectral capabilities of LANDSAT using classification methods, other processing techniques may still produce useful information.

7.6 Geometric Control and Data Set Recognition

As mentioned in the report, accurate location of LANDSAT pixels on maps produced from distorted aerial photographs was a very expensive process, not only financially but technically as well. A major problem in our study of Montana is that our field map was based on uncorrected aerial photomosaics. We underestimated the effect that parallax would have in rotation and mislocation of features, not to mention the difficulties in designing an evaluation procedure. Geometric considerations will continue to be a major source of error until improved geometric formatting compatible with available output devices is available, either on original data or in supplementary software. The need for compatibility of LANDSAT products with Geological Survey topographic maps or other base maps is of prime importance in research and operational efforts.

Mirrors placed in rain barrels (Evans, 1974) have been used to greatly facilitate the registration of LANDSAT information with base maps. More importantly, such a technique would allow excellent registration of two LANDSAT data sets for multitemporal processing or for continuous geometric fidelity. At least three mirrors are placed in the field in a plane normal to the path of the satellite. The spatial relationship of these mirrors to each other and to the control areas should be known accurately. These highly efficient reflectors should be recognized as very light spots on the images, or even automatically detectable in computer-applied geometry programs as spectrally uniform, high-valued points. For these reasons, we recommend that BLM initiate the selection of control areas in two or three Western U.S. regions, as a normal part of LANDSAT research.

Better location methods and larger plant communities will improve training and verification in future projects. The automatic recognition of plant communities in this project could likely have been improved considerably by such practices.

7.7 LANDSAT in Rangeland Management

1. The BLM should continue research into the abilities of LANDSAT data to provide range managers with information needed to improve its capability to control livestock grazing in a manner which will improve the vegetation and soil resource.

2. BLM should continue to use single channel, color composites, or ratio imagery on an operational basis wherever practical to educate resource managers about the format and capability of LANDSAT, and to stimulate ideas within BLM for the most effective use and additional requirements of these products.

We feel that LANDSAT data will be of great assistance to resource managers in collecting information on public lands. The Bureau of Land Management should conduct research and systems studies to anticipate their operational requirements and the relative technical merits of possible methods of data analysis. There are many and varied considerations which should enter into any system design. Some of them have been touched on even in our small effort to conduct limited studies in ephemeral and perennial rangeland environments.

1. LANDSAT data will have to be gathered, received, processed, and distributed in a timely fashion to be of use to range managers for other than trend analysis.
2. Geometric considerations and decisions about accuracy are very important and could alter greatly chances of success.
3. When automatic recognition is applied to LANDSAT data based on specified targets, spectral differences among targets are assumed to be discrete. The physical basis

for these differences, however, are not usually analyzed. As a result, the relationship between two targets is lost, and the basis for singularity of a target, whether it depends on ground cover, species, soil type, or a combination thereof, is lost to circumstantial statistical success.

4. Although we do report some limited recognition of the influence of plant species on LANDSAT signatures, our research indicates that whatever the decision rules applied, the spectral configuration of LANDSAT seems more sensitive to differences in vigorous vegetation than to actual physical and spectral differences among plant species.

APPENDIX A FIELD DATA ON PLANT COMMUNITIES

LOCATION OF TRANSECTS IN PLANT COMMUNITIES IN ARIZONA

1.	Site A	SWSE	Sec 35	T6N R9W	Sandy Draw
2.	Site A		Top Center of Sec 2	T5N R9W	Ridgetop
3.	Site A	SE	Sec 27	T6N R9W	Smooth Outwash Plain
4.	Site A	NW	Sec 34	T6N R9W	Rocky Hills
5.	Site B	NENE	Sec 33	T5N R9W	Steep Rocky North Slope
6.	Site B	NW	Sec 34	T5N R9W	Purplish Black Rocky Soil, Barren Area
7.	Site B	SENE	Sec 28	T5N R9W	Rocky Outwash Plain
8.	Site B	NWNW	Sec 28	T5N R9W	Flat Area just up out of Wash (Flood Plain?)
9.	Site C	NENW	Sec 23	T4N R10W	Black Rock Hill
9a.	Site C	SE	Sec 23	T4N R10W	Outwash Plain Light Soil Covered with Small Black Rocks
10.	Site C	NWNW	Sec 26	T4N R10W	Sandy Wash
11.	Site C	NWSW	Sec 22	T4N R10W	Smooth Outwash Plain
12.	Site C	NWSW	Sec 33	T4N R10W	Sandy Flat
13.	Site B				Mesquite Tree in Sandy Wash

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ARIZONA SITE A PLANT COMMUNITY No. 1

4-7-75

Map Area 1 — Latr, Frde Type

	No. of Hits	Percent Composition
Cercidium microphyllum	0	T
Larrea tridentata	6	75
Franseria deltoidea	1	12.5
Opuntia ramosissima	0	T
Prosopis juliflora	1	12.5
TOTAL	8	100.0

8% Ground Cover

ARIZONA SITE A PLANT COMMUNITY No. 2

4-7-75

Map Area 2 — Latr, Frdu Type

	No. of Hits	Percent Composition
Larrea tridendata	6	75
Fouquieria splendens	0	T
Franseria deltoidea	0	T
Franseria dumosa	2	25
Opuntia ramosissima	0	T
TOTAL	8	100

8% Ground Cover

ARIZONA SITE A PLANT COMMUNITY No. 3

4-8-75

Map Area 3 — Latr Type

	No. of Hits	Percent Composition
Franseria deltoidea	0	T
Franseria dumosa	0	T
Larrea tridentata	5	100
Opuntia basilaris	0	T
Opuntia ramosissima	0	T
TOTAL	5	100

5% Ground Cover

ARIZONA SITE A PLANT COMMUNITY No. 4

4-8-75

Map Area 4 — Opbi, Latr, Frde Type

	No. of Hits	Percent Composition
Acacia greggii	0	T
Carnegiea gigantea	0	T
Cercidium microphyllum	0	T
Franseria deltoidea	5	56
Franseria dumosa	0	T
Larrea tridentata	2	22
Lycium spp.	0	T
Opuntia basilaris	0	T
Opuntia bigelovii	1	11
Opuntia engelmannii	0	T
Opuntia ramosissima	1	11
Prosopis juliflora	0	T
TOTAL	9	100

9% Ground Cover

ARIZONA SITE A PLANT COMMUNITY No. 5

4-8-75

Map Area 5 — Cemi, Latr, Frde Type

	No. of Hits	Percent Composition
Carnegiea gigantea	0	T
Cercidium microphyllum	3	17
Ephedra trifurca	0	T
Fouquieria splendens	1	5
Franseria deltoidea	10	55
Franseria dumosa	T	T
Krameria spp.	0	T
Larrea tridentata	3	17
Opuntia ramosissima	1	6
TOTAL	18	100

18% Ground Cover

ARIZONA SITE A PLANT COMMUNITY No. 6

4-7-75

Map Area 6 — Cemi, Frdu, Latr, Cagi Type

	No. of Hits	Percent Composition
Acacia constricta	0	1
Carnegiea gigantea	0	T
Cercidium microphyllum	4	25
Condalia spathuloides	1	6
Ephedra trifurca	0	T
Eriogonum spp.	0	T
Fouquieria splendens	0	T
Franseria deltoidea	1	6
Franseria dumosa	4	25
Krameria spp.	0	T
Larrea tridentata	5	31
Lycium spp.	1	6
Opuntia ramosissima	0	T
TOTAL	16	100

16% Ground Cover

ARIZONA SITE A PLANT COMMUNITY No. 7

4-8-75

Map Area 7 Latr Type

	No. of Hits	Percent Composition
Franseria deltoidea	1	33
Larrea tridentata	2	67
Opuntia engelmannii	0	T
Opuntia ramosissima	0	T
Prosopis juliflora	0	T
TOTAL	3	100

3% Ground Cover

ARIZONA SITE A PLANT COMMUNITY No. 8

4-7-75

Map Area 8 Prju, Frde, Latr Type

	No. of Hits	Percent Composition
Acacia greggii	1	14
Franseria deltoidea	1	14
Larrea tridentata	3	43
Prosopis juliflora	2	29
	7	100

7% Ground Cover

ARIZONA SITE A PLANT COMMUNITY No. 9

4-8-75

Map Area 9 — Latr, Frdu Type

	No. of Hits	Percent Composition
Fouquieria splendens	0	T
Franseria dumosa	0	T
Larrea tridentata	3	100
Opuntia basilaris	0	T
Opuntia ramosissima	0	T
TOTAL	3	100

3% Ground Cover

ARIZONA SITE A PLANT COMMUNITY No. 10

4-8-75

Map Area 10 — Prju, Opra, Open Type

	No. of Hits	Percent Composition
Opuntia engelmannii	0	T
Opuntia ramosissma	0	T
Prosopis juliflora	3	100
TOTAL	3	100

3% Ground Cover

ARIZONA SITE A PLANT COMMUNITY No. 11

4-8-75

Map Area 11 Prju Type

	No. of Hits	Percent Composition
Acacia greggii	1	4
Larrea tridentata	3	13
Lycium spp.	1	4
Opuntia ramosissima	1	4
Prosopis juliflora	18	75
TOTAL	24	100

24% Ground Cover

ARIZONA SITE A PLANT COMMUNITY No. 12

4-8-75

Map Area 12 Prju, Frde, Latr Type

	No. of Hits	Percent Composition
Acacia constricta	0	T
Acacia greggii	0	T
Condalia lycioides	1	7
Franseria deltoidea	2	13
Hymenoclea salsola	0	T
Larrea tridentata	2	13
Lycium spp.	0	T
Prosopis juliflora	10	67
TOTAL	15	100

15% Ground Cover

ARIZONA SITE B PLANT COMMUNITY No. 1

4-10-75

Map Area 1 — Cemi, Latr, Frdu, Cagi Type

	No. of Hits	Percent Composition
Carnegiea gigantea	0	T
Cercidium microphyllum	5	28
Encelia farinosa	0	T
Ephedra fasciculata	0	T
Eriogonum spp.	0	T
Fouquieria splendens	1	5
Franseria deltoidea	1	5
Franseria dumosa	5	28
Hymenoclea salsola	0	T
Krameria spp.	0	T
Larrea tridentata	5	28
Lycium spp.	0	T
Olneya tesota	1	6
Opuntia bigelovii	0	T
Opuntia ramosissima	0	T
Tetracoccus hallii	0	T
TOTAL	18	100

18% Ground Cover

ARIZONA SITE B PLANT COMMUNITY No. 2

4-10-75

Map Area 2 — Cemi, Latr, Enfa, Fosp, Cagi
Cagi Type

	No. of Hits	Percent Composition
Acamptopappus sphaerocephalus	0	T
Bebbia juncea	0	T
Carnegiea gigantea	0	T
Cercidium microphyllum	6	32
Ditaxis lanceolata	0	T
Dyssodia porophylloides	0	T
Encelia farinosa	4	21
Eriogonum wrightii	1	5
Ferocactus spp.	0	T
Fouquieria splendens	1	5
Franseria dumosa	1	5
Hilaria rigida	1	5
Hyptis emoryi	0	T
Hymenoclea salsola	0	T
Krameria spp.	0	T

ARIZONA SITE B PLANT COMMUNITY No. 2
(Cont.)

Larrea tridentata	4	21
Lycium spp.	1	5
Menodora scabra	0	T
Opuntia bigelovii	0	T
Opuntia engelmanni	0	T
Opuntia ramosissima	0	1
Porophyllum gracile	0	T
Salazaria mexicana	0	T
Tetracoccus hallii	0	T
Trixis californica	0	T
Tridens muticus	0	T
Viguiera deltoidea	0	T
TOTAL	19	100

19% Ground Cover

ARIZONA SITE B PLANT COMMUNITY No. 3

4-10-75

Map Area 3 Cemi, Enfa, Cagi Type

	No. of Hits	Percent Composition
Carnegiea gigantea	0	T
Cercidium microphyllum	4	40
Encelia farinosa	2	20
Eriogonum wrightii	1	10
Fouquieria splendens	0	T
Franseria dumosa	2	20
Krameria spp.	1	10
Larrea tridentata	0	T
Opuntia biglovii	0	T
Viguiera deltoidea	0	T
TOTAL	10	100

10% Ground Cover

ARIZONA SITE B PLANT COMMUNITY No. 4

4-10-75

Map Area 4 — Cemi, Latr, Enfa, Fosp, Cagi Type

	No. of Hits	Percent Composition
Carnegiea gigantea	0	T
Cercidium microphyllum	4	22
Encelia farinosa	5	28
Eriogonum wrightii	0	T
Ferocactus spp.	0	T
Fouquieria splendens	1	5
Franseria dumosa	0	T
Hilaria rigida	1	5
Hyptis emoryi	0	T
Hymenoclea salsola	0	T
Krameria spp.	0	T
Larrea tridentata	6	33
Lycium spp.	0	T
Opuntia bigelovii	0	1
Opuntia ramosissima	0	1
Salazaria mexicana	0	T
Tetracoccus hallii	0	T
Trixis californica	0	T
Tridens muticus	1	5
Viguiera deltoidea	0	T
TOTAL	18	100

18% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 1

4-9-75

Map Area 1 — Latr, Frdu, Cemi, Cagi Type

	No. of Hits	Percent Composition
Carnegiea gigantea	0	T
Cercidium microphyllum	1	10
Fouquieria splendens	0	T
Franseria dumosa	2	20
Larrea tridentata	6	60
Olneya tesota	0	T
Opuntia arbuscula	1	10
Opuntia bigelovii	0	T
TOTAL	10	100

10% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 2

4-9-75

Map Area 2 (Wash or Arroya) Cemi, Olte, LYCI, Hysa Type

	No. of Hits	Percent Composition
Acacia gregii	2	8
Cercidium microphyllum	10	40
Franseria deltoidea	0	T
Franseria dumosa	0	T
Hymenoclea salsola	2	8
Larrea tridentata	2	8
Lycium spp.	5	20
Olneya tesota	4	16
Prosopis juliflora	0	T
TOTAL	25	100

25% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 3

4-9-75

Map Area 3 Cemi, Olte, LYCI, Hysa Type

	No. of Hits	Percent Composition
Carnegiea gigantea	0	T
Cercidium microphyllum	1	8
Fouquieria splendens	0	T
Franseria dumosa	3	23
Hymenoclea salsola	1	8
Larrea tridentata	5	38
Lycium spp.	1	7
Olneya tesota	1	8
Opuntia arbuscula	1	8
Opuntia bigelovii	0	T
TOTAL	13	100

13% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 4

4-9-75

Map Area 4 — Cemi, Olte, Latr, Cagi Type

	No. of Hits	Percent Composition
Carnegiea gigantea	0	T
Cercidium microphyllum	2	17
Franseria dumosa	2	17
Larrea tridentata	7	58
Lycium spp.	1	8
Olneya tesota	0	T
Opuntia arbuscula	0	T
Opuntia bigelovii	0	T
TOTAL	12	100

12% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 5

4-9-75

Map Area 5 — Cemi, Enfa, Opbi, Cagi Type

	No. of Hits	Percent Composition
Carnegiea gigantea	0	T
Cercidium microphyllum	1	9
Encelia farinosa	3	25
Ferocactus spp.	1	8
Fouquieria splendens	0	T
Krameria spp.	0	T
Larrea tridentata	6	50
Opuntia bigelovii	1	8
Opuntia ramosissima	0	T
TOTAL	12	100

12% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 6

4-9-75

Map Area 6

Cemi, Latr, Cagi Type

	No. of Hits	Percent Composition
Carnegiea gigantea	0	T
Cercidium microphyllum	3	21
Fouquieria splendens	0	T
Franseria dumosa	3	21
Larrea tridentata	6	43
Lycium spp.	0	T
Olneya tesota	1	7
Opuntia arbuscula	1	8
TOTAL	14	100

14% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 7

4-9-76

Map Area 7

Latr, Frdu, Cemi, Olte Type

	No. of Hits	Percent Composition
Cercidium microphyllum	0	T
Franseria dumosa	1	15
Hymenoclea salsola	0	T
Larrea tridentata	4	57
Lycium spp.	1	14
Olneya tesota	0	T
Opuntia arbuscula	1	14
Opuntia bigelovii	0	T
TOTAL	7	100

7% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 8

4-9-75

Map Area 8

Cemi, Olte, Latr, Cagi Type

	No. of Hits	Percent Composition
Carnegiea gigantea	0	T
Cercidium microphyllum	2	22
Ferocactus spp.	0	T
Fouquieria splendens	0	T
Franseria dumosa	1	11
Larrea tridentata	6	67
Olneya tesota	0	T
Opuntia arbuscula	0	T
Opuntia bigelovii	0	T
TOTAL	9	100

9% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 9

4-9-75

Map Area 9

Latr, Frdu, Olte Type

	No. of Hits	Percent Composition
Cercidium microphyllum	0	T
Ferocactus spp.	0	T
Franseria deltoidea	0	T
Franseria dumosa	1	20
Larrea tridentata	3	60
Olneya tesota	0	T
Opuntia arbuscula	1	20
TOTAL	5	100

5% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 10

4-9-75

Map Area 10 — Cemi, Olte, Latr, Frde Type

	No. of Hits	Percent Composition
Carnegiea gigantea	0	T
Cercidium microphyllum	1	13
Ferocactus spp.	0	T
Franseria deltoidea	3	38
Franseria dumosa	1	12
Larrea tridentata	2	25
Olneya tesota	1	12
Opuntia arbuscula	0	T
Opuntia ramosissima	0	T
TOTAL	8	100

8% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 11

4-9-75

Map Area 11 — Latr, Frdu Type

	No. of Hits	Percent Composition
Franseria dumosa	1	25
Larrea tridentata	3	75
TOTAL	4	100

4% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 12

4-9-75

Map Area 12 — Latr Type

	No. of Hits	Percent Composition
Larrea tridentata	2	100
Olneya tesota	0	T
Prosopis juliflora	0	T
TOTAL	2	100

2% Ground Cover

ARIZONA SITE C PLANT COMMUNITY No. 13

4-9-75

Map Area 13 — Cemi, Olte, Latr, Cagi Type

	No. of Hits	Percent Composition
Carnegiea gigantea	0	T
Cercidium microphyllum	0	T
Franseria deltoidea	1	11
Franseria dumosa	2	22
Larrea tridentata	5	56
Lycium spp.	0	T
Olneya tesota	0	T
Opuntia arbuscula	0	T
Opuntia biglovii	1	11
TOTAL	9	100

9% Ground Cover

LOCATION OF TRANSECTS IN PLANT COMMUNITIES IN MONTANA

LISCOM CREEK-SITE 4

1.	NESW	Sec 23	T1N R45E	Swale East of Creek
2.	NESW	Sec 23	T1N R45E	Ridgetop East of Creek
3.	NWSW	Sec 23	T1N R45E	Gently Sloping Valley
4.	NWNW	Sec 24	T1N R45E	Sidehill Northfacing Slope
5.	SENW	Sec 25	T1N R45E	Ridgetop
6.	SENW	Sec 25	T1N R45E	Steep Sidehill
7.	SWNE	Sec 25	T1N R45E	Flat near Reservoir
8.	NESE	Sec 24	T1N R45E	Rehabilitated Coal Mine Fire Area
9.	SESE	Sec 14	T1N R45E	Alfalfa and Grass Hayfield

ALLEN RANCH-SITE 5

1.	SENW	Sec 6	T1N R50E	Ridgetop
2.	NWSW	Sec 6	T1N R50E	Ridgetop (barren)
3.	NWSW	Sec 6	T1N R50E	Slope Adjacent to Ridgetop
4.	NWSE	Sec 1	T1N R49E	Gently Sloping Valley
5.	NWSW	Sec 6	T1N R50E	Fairly Steep Sidehill

SCOTT RANCH-SITE 6

1.	SENE	Sec 15	T2N R53E	Ridgetop
2.	SENE	Sec 15	T2N R53E	Gently Sloping Valley
3.	SENE	Sec 15	T2N R53E	Narrow Draw, Drainage Channel
4.	NESW	Sec 10	T2N R53E	Seeded Grass Pasture
5.	Sec Corner, Common to Corners	8,9,16,17	R2N R53E	Ridgetop (barren)
6.	Sec Corner Common to Corners	8,9,16,17	T2N R53E	Gently Sloping Sidehill

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 1

6-16-75

Silver Sage - Grass Bottom SWNE Sec. 25, T1N, R45E

	No. of Hits		Percent Composition	
Bare ground	43			
Litter	5			
Rock	0			
		48		
Agropyron smithii	3		6	
Agropyron spicatum	0		T	
Aristida longiseta	1		2	
Bouteloua gracilis	2		4	
Bromus tectorum	1		2	
Koeleria cristata	11		21	
Poa secunda	0		T	
Stipa comata	4		8	
Stipa viridula	0		T	
		22		43
Achillea millefolium	0		T	
Erysimum asperum	0		T	
Linum lewisii	1		2	
Lupinus sericeus	0		T	
Sphaeralcea coccinea	1		2	
Taraxacum officinale	7		13	
Tragopogon dubius	1		2	
		10		19
Artemisia cana	14		27	
Artemisia frigida	1		2	
Gutierrezia sarothrae	3		5	
Phlox hoodii	2		4	
		20		38
TOTAL		100		100

52% Ground Cover
Arca, Kocr, Stco Type

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 2

6-16-75

Barren Hillside

SE Sec. 18, T1N, R45 E

	No. of Hits		Percent Composition	
Bare ground	85			
Litter	T			
Rock	T			
		85		
Agropyron spicatum	2		13	
		2		13
Linum lewisii	0		T	
Petalostemon candidum	0		T	
Vicia americana	2		13	
		2		13
Atriplex confertifolia	0		T	
Chrysothamnus nauseosus	2		13	
Eriogonum multiceps	2		13	
Gutierrezia sarothrae	4		28	
Hymenoxys spp.	0		T	
Phlox hoodii	2		13	
Rhus trilobata	1		7	
Rosa woodsii	0		T	
		11		74
TOTAL		100		100

15% Ground Cover
Chna, Atco, Gusa Type

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 3

6-16-75

Upland Grass NE Sec. 19, T1N, R46E

	No. of Hits		Percent Composition	
Bare ground	22			
Litter	32			
Rock	0			
		54		
Aristida longiseta	1		2	
Bouteloua gracilis	6		13	
Bromus tectorum	2		4	
Calamovilfa longifolia	1		2	
Koeleria cristata	3		7	
Poa secunda	3		7	
Stipa comata	5		11	
		21		46
Carex eleocharis	7		15	
Carex filifolia	3		7	
		10		22
Achillia lanulosa	T		T	
Artemisia ludoviciana	4		9	
Astragalus spp.	0		T	
Iva axillaris	1		2	
Penstemon spp.	0		T	
Psoralea esculenta	0		T	
Sphaeralcea coccinea	2		4	
Taraxacum officinale	2		4	
Zigadenus spp.	2		4	
		11		23
Artemisia cana	0		T	
Artemisia frigida	1		2	
Rhus trilobata	3		7	
		4		9
TOTAL		100		100

46% Ground Cover

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 4

6-16-75

Pine - Bunchgrass

NW Sec. 24, T1N, R45E

	No. of Hits		Percent Composition	
Bare ground	4			
Litter	36			
Big rock	3			
		43		
Agropyron spicatum	8		14	
Andropogon scoparius	2		3	
Aristida longiseta	1		2	
Bouteloua curtipendula	1		2	
Koeleria cristata	2		3	
Poa secunda	1		2	
Stipa viridula	1		2	
		16		28
Carex eleocharis	2		3	
Carex filifolia	1		2	
		3		5
Achillea millefolium	1		2	
Chrysopsis villosa	1		2	
Geum triflorum	0		T	
Leucocrinum montanum	0		T	
Linum lewisii	0		T	
Lupinus sericeus	0		T	
Tragopogon dubius	0		T	
		2		4
Artemisia cana	1		2	
Artemisia frigida	1		2	
Juniperus scopulorum	3		5	
Phlox hoodii	1		2	
Pinus ponderosa	27		47	
Rosa woodsii	0		T	
Rhus trilobata	2		3	
Symphoricarpos occidentalis	1		2	
		36		63
TOTAL		100		100

57% Ground Cover

Pipo, Agsp, Rhtr Type

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 5

6-16-75

Ridgetop SENW Sec. 25, T1N, R45E

	No. of Hits		Percent Composition	
Bare ground	46			
Litter	16			
Small rock	6			
		68		
Agropyron spicatum	0		T	
Bouteloua gracilis	9		28	
Koeleria cristata	0		T	
		9		28
Carex filifolia	15		47	
		15		47
Artemisia dracunculoides	3		9	
Penstemon spp.	0		T	
Psoralea esculenta	0		T	
Sphaeralcea coccinea	0		T	
Vicia americana	0		T	
Zigadenus spp.	1		3	
		4		12
Artemisia frigida	4		13	
		4		13
TOTAL		100		100

32% Ground Cover
Cafi, Bogr, Arfr Type

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 6

6-16-75

Bluestem Hillside SENW Sec. 25, T1N, R45E

	No. of Hits		Percent Composition	
Bare ground	29			
Litter	15			
Small rock	8			
Large rock	1			
		53		
Agropyron spicatum	1		2	
Andropogon gerardii	4		9	
Andropogon scoparius	23		49	
Bouteloua curtipendula	1		2	
Bouteloua gracilis	6		13	
Calamovilfa longifolia	0		T	
		35		75
Carex eleocharis	1		2	
Carex filifolia	2		4	
		3		6
Artemisia dracunculoides	1		2	
Artemisia ludoviciana	2		4	
Astragalus spp.	1		2	
Castilleja sessiliflora	0		T	
Psoralea esculenta	0		T	
		4		8
Artemisia frigida	0		T	
Juniperus horizontalis	0		T	
Rhus trilobata	1		2	
Yucca glauca	4		9	
		5		11
TOTAL		100		100

47% Ground Cover
Ansc, Juho, Yugl Type

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 7

6-16-75

Grass - Dandelion Bottom SESW Sec. 24, T1N, R45E

	No. of Hits		Percent Composition	
Bare ground	39			
Litter	8			
Rock	0			
		47		
Agropyron smithii	6		11	
Aristida longiseta	0		T	
Bouteloua gracilis	16		30	
Bromus tectorum	3		6	
Poa secunda	0		T	
		25		47
Leucocrinum montanum	1		2	
Taraxacum officinale	26		49	
Tragopogon dubius	1		2	
		28		53
Artemisia frigida	0		T	
		0		T
TOTAL		100		100

53% Ground Cover
Taof, Bogr, Agsm Type

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 8

6-16-75

Coal Mine Fire Rehab. Area NESE Sec. 24, T1N, R45E

	No. of Hits		Percent Composition	
Bare ground	80			
Litter	4			
Rock	T			
		84		
Agropyron cristatum	8		50	
Agropyron spicatum	0		T	
Bromus tectorum	4		25	
Koeleria cristata	0		T	
Poa secunda	0		T	
Stipa comata	0		T	
		12		75
Artemisia ludoviciana	0		T	
Astragalus spp.	0		T	
Circium vulgare	0		T	
Cryptantha braduriana	0		T	
Linum lewisii	0		T	
Penstemon spp.	0		T	
		0		0
Artemisia cana	0		T	
Artemisia frigida	2		13	
Gutierrezia sarothrae	2		12	
Phlox hoodii	0		T	
		4		25
TOTAL		100		100

16% Ground Cover
Agcr, Gusa, Arca Type

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 1

6-17-75

Ridgetop NW Sec. 6, T1N, R50E

	No. of Hits		Percent Composition	
Bare ground	32			
Litter	11			
Small rock	12			
Large rock	2			
		57		
Agropyron smithii	1		2	
Agropyron spicatum	1		2	
Aristida longiseta	0		T	
Bouteloua gracilis	4		9	
Koeleria cristata	8		19	
Stipa comata	2		5	
Stipa viridula	3		7	
		19		44
Carex filifolia	2		5	
		2		5
Artemisia campestris	1		2	
Artemisia dracunculoides	1		2	
Astragalus spp.	3		7	
Iva axillaris	2		5	
Leucocrinum montanum	1		2	
Penstemon spp.	0		T	
Psoralea esculenta	0		T	
Tragopogon dubius	2		5	
		10		23
Artemisia cana	3		7	
Artemisia frigida	4		10	
Gutierrezia sarothrae	1		2	
Phlox hoodii	4		9	
		12		28
TOTAL		100		100

43% Ground Cover

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 2

6-17-75

Barren Hillside SWSW Sec. 1, T1N, R49E

	No. of Hits		Percent Composition	
Bare ground	63			
Litter	0			
Small rock	10			
Large rock	11			
		84		
Agropyron spicatum	4		25	
Andropogon scoparius	1		6	
Bouteloua curtipendula	1		6	
Stipa viridula	1		6	
		7		43
Artemisia dracunculoides	0		T	
Iva axillaris	1		6	
Vicia americana	0		T	
		1		6
Artemisia tridentata	2		13	
Atriplex confertifolida	2		13	
Gutierrezia sarothrae	1		6	
Rhus trilobata	2		13	
Yucca glauca	1		6	
		8		51
TOTAL		100		100

16% Ground Cover

ALLEN - MONTANA PLANT COMMUNITY No. 3

6-17-75

Grass - Yucca Rolling Hills SENE Sec. 1, T1N, R49E

	No. of Hits		Percent Composition	
Bare ground	34			
Litter	27			
Small rock	0			
Large rock	0			
		61		
Bouteloua gracilis	5		13	
Bromus tectorum	0		T	
Calamovilfa longifolia	0		T	
Koeleria cristata	5		13	
Poa secunda	0		T	
Stipa comata	4		10	
Stipa viridula	6		16	
		20		52
Carex eleocharis	1		2	
Carex filifolia	10		26	
		11		28
Artemisia dracunculoides	0		T	
Artemisia ludoviciana	0		T	
Astragalus spp.	0		T	
Chrysopsis villosa	0		T	
Penstemon spp.	0		T	
Psoralea esculenta	1		2	
Solidago spp.	0		T	
Sphaeralcea coccinea	0		T	
Tragopogon dubius	0		T	
		1		2
Juniperus horizontalis	0		T	
Phlox hoodii	0		T	
Rosa woodsii	1		2	
Yucca glauca	6		16	
TOTAL		7 / 100		18 / 100
39% Ground Cover				

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 4

6-17-75

Grass Flat

SESW Sec. 1, T1N, R49E

	No. of Hits		Percent Composition	
Bare ground	14			
Litter	34			
Small rock	0			
Large rock	0			
		48		
Agropyron dasystachyum	0		T	
Agropyron smithii	4		8	
Aristida longiseta	1		2	
Bouteloua gracilis	19		36	
Bromus tectorum	8		15	
Calamovilfa longifolia	1		2	
Koeleria cristata	9		17	
Poa secunda	0		T	
		42		80
Carex filifolia	2		4	
		2		4
Achillea millefolium	0		T	
Chrysopsis villosa	0		T	
Cirsium spp.	0		T	
Haplopappus spinulosus	0		T	
Leucocrinum montanum	0		T	
Melilotus officinalis	2		4	
Psoralea esculenta	1		2	
Taraxacum officinale	3		6	
Tragopogon dubius	2		4	
		8		16
Artemisia frigida	0		T	
Phlox hoodii	0		T	
		0		T
TOTAL		100		100

52% Ground Cover

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 5

6-17-75

Bluestem Hillside NW Sec. 6 T1N, R50E

	No. of Hits		Percent Composition	
Bare ground	17			
Litter	9			
Small rock	21			
Large rock	13			
		60		
Agropyron spicatum	1		3	
Andropogon scoparius	16		40	
Bouteloua curtipendula	0		T	
Bouteloua gracilis	2		5	
Koeleria cristata	2		5	
Poa secunda	1		3	
		22		56
Carex filifolia	1		3	
		1		3
Artemisia campestris	1		2	
Astragalus spp.	1		2	
Echinacea angustifolia	2		5	
Lupine spp.	1		2	
		5		11
Artemisia frigida	3		8	
Juniperus horizontalis	7		18	
Phlox hoodii	1		2	
Yucca glauca	1		2	
		12		30
TOTAL		100		100

40% Ground Cover

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 7

6-17-75

Sage - Grass Upland | SENE Sec. 11, TIN, R49E

	No. of Hits		Percent Composition	
Bare ground	24			
Litter	18			
Small rock	0			
Large rock	0			
		42		
Agropyron smithii	4		7	
Agropyron spicatum	1		2	
Bouteloua gracilis	5		9	
Bromus tectorum	3		5	
Koeleria cristata	8		14	
Stipa comata	1		2	
Stipa viridula	6		10	
		28		49
Carex filifolia	2		3	
		2		3
Achillia millefolium	0		T	
Antennaria neglecta	2		3	
Artemisia dracunculoides	0		T	
Leucocrinum montanum	0		T	
Psoralea esculenta	1		2	
Sphaeralcea coccinea	1		2	
Vicia americana	1		2	
		5		9
Artemisia cana	5		8	
Artemisia frigida	7		12	
Artemisia tridentata	8		14	
Gutierrezia sarothrae	2		3	
Phlox hoodii	1		2	
		23		39
TOTAL		100		100

58% Ground Cover

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 8

6-17-75

Silver Sage - Grass Stringer SENE Sec. 11, TIN, R49E

	No. of Hits		Percent Composition	
Bare ground	21			
Litter	15			
Small rock	0			
Large rock	1			
		37		
Agropyron smithii	5		8	
Andropogon scoparius	1		1	
Bouteloua gracilis	12		19	
Buchloe dactyloides	1		2	
Koeleria cristata	3		5	
Poa secunda	5		8	
Stipa viridula	4		6	
		31		49
Carex filifolia	1		2	
		1		2
Melilotus officinalis	5		8	
Psoralea esculenta	0		T	
Taraxacum officinale	2		3	
Tragopogon dubius	0		T	
Zigadenus spp.	1		2	
		8		13
Artemisia cana	9		14	
Artemisia frigida	2		3	
Artemisia tridentata	4		6	
Eurotia lanata	2		3	
Eriogonum spp.	0		T	
Gutierrezia sarothrae	3		5	
Phlox hoodii	2		3	
Rosa woodsii	1		2	
		23		36
TOTAL		100		100
63% Ground Cover				

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 9

6-17-75

Pine - Bunchgrass SWSW Sec. 1, TIN, R49E

	No. of Hits		Percent Composition	
Bare Ground	5			
Litter	26			
Small rock	8			
Large rock	2			
		41		
Agropyron smithii	1		2	
Agropyron spicatum	4		7	
Andropogon scoparius	0		T	
Bouteloua curtipendula	1		2	
Bouteloua gracilis	5		8	
Stipa viridula	8		13	
		19		32
Achillea millefolium	1		2	
Allium spp.	0		T	
Artemisia dracunculoides	0		T	
Astragalus spp.	0		T	
Helianthus annuus	0		T	
Leucocrinum montanum	1		2	
Psoralea esculenta	0		T	
Taraxacum officinale	1		2	
Vicia americana	0		T	
		3		6
Artemisia cana	0		T	
Chrysothamnus nauseosus	0		T	
Juniperus horizontalis	3		5	
Juniperus scopulorum	3		5	
Mahonia repens	0		T	
Pinus ponderosa	25		42	
Rhus trilobata	3		5	
Symphoricarpos occidentalis	2		3	
Yucca glauca	1		2	
		37		62
TOTAL		100		100

59% Ground Cover

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 1

6-23-75

Ridgetop (NW) SWSE Sec. 5, T2N, R53E

	No. of Hits		Percent Composition	
Bare ground	58			
Litter	5			
Small rock	2			
Large rock	0			
		65		
Agropyron smithii	4		11	
Bouteloua gracilis	3		9	
Calamovilfa longifolia	0		T	
Koeleria cristata	2		6	
		9		26
Carex filifolia	2		6	
		2		6
Allium spp.	0		T	
Musineon divericatum	0		T	
Psoralea esculenta	1		3	
Tragopogon dubius	0		T	
Vicia americana	3		8	
		4		11
Artemisia frigida	4		11	
Artemisia tridentata	2		6	
Atriplex confertifolia	3		8	
Eriogonum spp.	2		6	
Eurotia lanta	1		3	
Grindelia squarrosa	0		T	
Gutierrezia sarothrae	5		14	
Opuntia spp.	0		T	
Phlox hoodii	1		3	
Sarcobatus vermiculatus	2		6	
		20		57
TOTAL		100		100

35% Ground Cover

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 2

6-23-75

Rolling Hill Grassland

NWNE Sec. 8, T2N, R53E

	No. of Hits		Percent Composition	
Bare ground	38			
Litter	32			
Small rock	0			
Large rock	0			
		70		
Agropyron smithii	8		27	
Agropyron spicatum	0		T	
Bouteloua gracilis	16		53	
Bromus tectorum	2		7	
Distichlis stricta	1		3	
Koeleria cristata	0		T	
Poa secunda	0		T	
		27		90
Carex filifolia	0		T	
		0		T
Achillea millefolium	1		3	
Astragalus spp.	0		T	
Erigeron spp.	0		T	
Psoralea esculenta	0		T	
Sphaeralcea coccinea	0		T	
Taraxacum officinale	1		4	
Vicia americana	0		T	
		2		7
Artemisia frigida	0		T	
Opuntia spp.	1		3	
Sarcobatus vermiculatus	0		T	
		1		3
TOTAL		100		100

30% Ground Cover

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 4

6-23-75

Seeded Grass Bottomland NESW Sec. 10, T2N, R53E

	No. of Hits		Percent Composition	
Bare ground	45			
Litter	13			
Small rock	0			
Large rock	0			
		58		
Agropyron cristatum	18		43	
Agropyron smithii	3		7	
Bouteloua gracilis	8		19	
Bromus tectorum	3		7	
Poa pratensis	4		10	
Poa secunda	0		T	
		36		86
Melilotus officinalis	1		2	
Plantago purshii	2		5	
Taraxacum officinale	1		3	
Vicia americana	1		2	
		5		12
Artemisia cana	1		2	
Artemisia frigida	0		T	
		1		2
TOTAL		100		100

42% Ground Cover

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 5

6-23-75

Barren Hillside NESW Sec. 15, T2N, R53E

	No. of Hits		Percent Composition	
Bare ground	47			
Litter	6			
Small rock	10			
Large rock	3			
		66		
Agropyron dasystachyum	1		3	
Agropyron smithii	5		15	
Agropyron spicatum	2		6	
Agropyron trachycaulum	1		2	
Koeleria cristata	0		T	
Poa secunda	0		T	
		9		26
Carex filifolia	0		T	
		0		T
Achillea millefolium	0		T	
Allium spp.	0		T	
Astragalus spp.	0		T	
Lomatium foeniculaceum	1		3	
Penstemon grandiflorus	0		T	
Psoralea esculenta	0		T	
Vicia americana	0		T	
		1		3
Artemisia tridentata	10		29	
Atriplex confertifolia	4		12	
Atriplex nuttallii	3		9	
Chrysothamnus nauseosus	1		3	
Gutierrezia sarothrae	5		15	
Phlox hoodii	0		T	
Sarcobatus vermiculatus	1		3	
		24		71
TOTAL		100		100

34% Ground Cover

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 6

6-23-75

Arca-Artr-Grass   Rolling Hills   SESE Sec. 8, T2N, R53E

	No. of Hits		Percent Composition	
Bare ground	29			
Litter	19			
Small rock	0			
Large rock	0			
		48		
Agropyron dasystachyum	1		2	
Agropyron smithii	0		T	
Andropogon scoparius	0		T	
Aristida longiseta	1		2	
Bouteloua gracilis	13		25	
Bromus tectorum	0		T	
Koeleria cristata	2		4	
Poa secunda	0		T	
Stipa viridula	2		4	
		19		37
Carex eleocharis	1		2	
Carex filifolia	2		4	
		3		6
Achillea millefolium	0		T	
Artemisia ludoviciana	0		T	
Astragalus spp.	2		4	
Chrysopsis villosa	0		T	
Erigeron spp.	0		T	
Oenothera caespitosa	0		T	
Psoralea esculenta	2		4	
Selaginella densa	3		5	
Sphaeralcea coccinea	0		T	
Taraxacum officinale	3		6	
Tragopogon dubius	0		T	
Vicia americana	0		T	
		10		19
Artemisia cana	8		15	
Artemisia frigida	3		6	
Artemisia tridentata	7		13	
Gutierrezia sarothrae	1		2	
Opuntia spp.	0		T	

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 6
(Cont.)

Phlox hoodii	1		2	
Rosa woodsii	0		T	
Sarcobatus vermiculatus	0		T	
Symphoricarpos occidentalis	0		T	
		20		38
TOTAL		100		100

52% Ground Cover

SCOTT RANCH - MONTANA PLANT COMMUNITY No.7

6-23-75

Silver Sage - Grass Bottom   SWNE Sec. 16, T2N, R53E

	No. of Hits		Percent Composition	
Bare ground	1			
Litter	22			
Small rock	0			
Large rock	0			
		23		
Agropyron smithii	8		10	
Bouteloua gracilis	8		11	
Bromus tectorum	1		1	
Poa secunda	3		4	
		20		26
Carex filifolia	0		T	
		0		T
Achillea millefolium	8		11	
Sphaeralcea coccinea	0		T	
Taraxacum officinale	1		1	
		9		12
Artemisia cana	40		52	
Artemisia frigida	1		1	
Artemisia tridentata	2		3	
Symphoricarpos occidentalis	5		6	
		48		62
TOTAL		100		100

77% Ground Cover

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 8

6-23-75

Ridgetop (SE)

NESW Sec. 15, T2N, R53E

	No. of Hits		Percent Composition	
Bare ground	53			
Litter	1			
Small rock	14			
Large rock	4			
		72		
Agropyron spicatum	2		7	
Agropyron trachycaulum	5		18	
Bouteloua gracilis	0		T	
		7		25
Astragalus spp.	4		14	
Suaeda depressa	2		7	
Vicia americana	0		T	
		6		21
Artemisia frigida	0		T	
Artemisia tridentata	2		7	
Atriplex nuttallii	5		18	
Grindelia squarrosa	1		4	
Gutierrezia sarothrae	7		25	
Phlox hoodii	0		T	
		15		54
TOTAL		100		100

28% Ground Cover

APPENDIX B VEGETATION AND SOIL DATA COMPILATION

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ARIZONA SITE PLANT LIST

Symbol	Scientific Name	Common Name
Acco	Acacia constricta	Whitethorn
Acgr	Acacia greggii	Catclaw
Acsp	Acamptopappus sphaerocephalus	Golden-Head
Boba	Bouteloua barbata	Sixweeks grama
Beju	Bebbia juncea	Rush bebbia
Cagi	Carnegiea gigantea	Saguaro
Cemi	Cercidium microphyllum	Littleaf paloverde
Coly	Condalia lycioides	Gray-thorn
Cosp	Condalia spathuloides	Squawbush
Crma	Cryptantha maritima	Cryptantha
Dila	Ditaxis lanceolata	Silver bush
Dypo	Dyssodia porophylloides	Dyssodia
Enfa	Encelia farinosa	Brittlebush
Epfa	Ephedra fasciculata	Fascicled ephedra
Eptr	Ephedra trifurca	Three-fork ephedra
Erci	Erodium cicutarium	Filaree
ERIO	Eriogonum spp.	Buckwheat
Epwr	Eriogonum wrightii	Wright buckwheat
Feoc	Festuca octoflora	Sixweeks fesue
FERO	Ferocactus spp.	Bisnaga
Fosp	Fouquieria splendens	Ocotillo
Frde	Franseria deltoidea	Green bursage
Frdu	Franseria dumosa	White bursage
Hiri	Hilaria rigida	Big galleta
Hyem	Hyptis emoryi	Bee-sage
Hysa	Hymenoclea salsola	White burrobrush
KRAM	Krameria spp.	Range ratany
Latr	Larrea tridentata	Creosote bush
LYCI	Lycium spp.	Wolf-berry
Mesc	Menodora scabra	Smooth menodora
Olte	Olneya tesota	Ironwood
Opar	Opuntia arbuscula	Pencil cholla

ARIZONA SITE PLANT LIST
(Cont.)

Opba	Opuntia basilaris	Beavertail cactus
Opbi	Opuntia bigelovii	Teddybear cholla
Open	Opuntia engelmannii	Engelmann prickly-pear
Opra	Opuntia ramosissima	Purple cholla
Plpu	Plantago purshii	Indian-wheat
Pogr	Porophyllum gracile	Yerba-del-venado
Prju	Prosopis juliflora	Honey mesquite
Same	Salazaria mexicana	Bladder-sage
Teha	Tetracoccus hallii	Chuckawalla bush
Trca	Trixis californica	California trixis
Trmu	Tridens muticus	Slim tridens
Vide	Viguiera deltoidea	Desert-sunflower

SOIL COMPOSITION IN ARIZONA

SOIL		% Sandy Loam	% Sandy Gravelly Loam	% Light Rock	% Dark Rock	% Purple Rock or Soil
1	A		15	85		
2	B	50		50		
3	C		10	45	45	
4	D		25	37.5	37.5	
5	E		10	45	45	
6	G		10	45	45	
7	H					15% Soil 100=85% Rock
8	J	20			80	
9	K		55	22.5	22.5	
10	L	99		1		
11	P&M	97.5		2.5		
12	P,N,R	66	32	2		
13	O	70		15	15	
14	P	98		2		
15	Q		90	10		
16	R	100				
17	S		70		30	
18	T		95	2.5	2.5	
19	V	60	20	20		
20	W	100				
21	Y		85	15		
22	M	97		3		
23	N		95	5		

MONTANA SITE PLANT LIST

Symbol	Scientific Name	Common name
Acla	Achillia lanulosa	Western yarrow
Acmi	Achillia millefolium	Western yarrow
Agcr	Agropyron cristatum	Crested wheatgrass
Agda	Agropyron dasystachyum	Thickspike wheatgrass
Agsm	Agropyron smithii	Western wheatgrass
Agsp	Agropyron spicatum	Bluebunch wheatgrass
Agtr	Agropyron trachycaulum	Slender wheatgrass
ALLI	Allium spp.	Wild onion
Ange	Andropogon gerardii	Big Bluestem
Anne	Antennaria neglecta	Field pussytoes
Ansc	Andropgon scoparius	Little bluestem
Arca	Artemisia cana	Silver sage
Arca	Artemisia campestris	Green sagewort
Ardr	Artemisia dracunculoides	Falsetarragon sagewort
Arfr	Artemisia frigida	Fringed sage
Arlo	Aristida longiseta	Red three-awn
Arlu	Artemisia ludoviciana	Cudweed sagewort
Artr	Artemisia tridentata	Big sagebrush
ASTRA	Astragalus spp.	Locoweed
Atco	Atriplex confertifolia	Shadscale
Atnu	Atriplex nuttallii	Nuttall saltbush
Bocu	Bouteloua curtipendula	Side-oats grama
Bogr	Bouteloua gracilis	Blue grama
Brte	Bromus tectorum	Cheatgrass
Buda	Buchloe dactyloides	Buffalo grass
Cael	Carex eleocharis	Needleleaf sedge
Cafi	Carex filifolia	Threadleaf sedge
Calo	Calamovilfa longifolia	Prairie sandreed
Case	Castileja sessiliflora	Downy paintbrush
Chna	Chrysothamnus nauseosus	Rubber rabbitbrush
Chvi	Chrysopsis villosa	Hairy goldenaster

CIRS	Cirsium spp.	Thistle
Civu	Cirsium vulgare	Bull thistle
Crbr	Cryptantha bradburiana	Miners candle
Dist	Distichlis stricta	Desert saltgrass
Escan	Echinacea angustifolia	Black sampson
Eras	Erysiumum asperum	Western wallflower
ERIG	Erigeron spp.	Fleabane
ERIO	Eriogonum spp.	Buckwheat
Ermu	Eriogonum multiceps	Buckwheat
Eula	Eurotia lanata	Winterfat
Getr	Geum triflorum	Prairiesmoke
Grsq	Grindelia squarrosa	Curlycup gumweed
Gusa	Gutierrezia sarothrae	Broom snakeweed
Hasp	Haplopappus spinulosus	Cutleaf goldenweed
Hean	Helianthus annuus	Common sunflower
HYME	Hymenoxys spp.	Hymenoxys
Ivax	Iva axillaris	False ragweed
Juho	Juniperus horizontalis	Prostrate juniper
Jusc	Juniperus scopulorum	Rocky Mtn. juniper
Kocr	Koeleria cristata	Junegrass
Lemo	Leucocrinum montanum	Common starlily
Lile	Linum lewisii	Blue flax
Lofo	Lomatium foeniculaceum	Plains lomatium
LUPI	Lupinus spp.	Lupine
Luse	Lupinus sericeus	Silky lupine
Mare	Mahonia repens	Creeping mahonia
Meof	Melilotus officinalis	Yellow sweetclover
Mudi	Musineon divericatum	Wild parsley
Oeca	Oenothera caespitosa	Gumbo lily
OPUN	Opuntia spp.	Beavertail cactus
Peca	Petalostemon candidum	White prairie-clover
Pegr	Penstemon grandiflorus	Shell-leaf penstemon
PENS	Penstemon spp.	Penstemon
Phho	Phlox hoodii	Hood's phlox

MONTANA SITE PLANT LIST
(Cont.)

Pipo	Pinus ponderosa	Ponderosa pine
Plpu	Plantago purshii	Wooly Indianwheat
Popr	Poa pratensis	Kentucky bluegrass
Pose	Poa secunda	Sandberg bluegrass
Pses	Psoralea esculenta	Common bredroot scurfpea
Rhtr	Rhus trilobata	Skunkbush
Rowo	Rosa woodsii	Wild rose
Save	Sarcobatus vermiculatus	Greasewood
Sede	Selaginella densa	Selaginella
SOLI	Solidago spp.	Goldenrod
Spco	Sphaeralcea coccinea	Scarlet globemallow
Stco	Stipa comata	Needle-and-thread
Stvi	Stipa viridula	Green needlegrass
Sude	Suaeda depressa	Seepweed
Syoc	Symphoricarpos occidentalis	Western snowberry
Taof	Taraxacum officinale	Common dandelion
Trdu	Tragopogon dubius	Yellow salsify
Viam	Vicia americana	American vetch
Yugl	Yucca glauca	Yucca
ZIGA	Zigadenus spp.	Deathcamas

1975 ARIZONA PHENOLOGY

Plant Name	Phenological Stage 4/5-11	5/10-11
Acacia greggii		
Baileya multiradiata	Plants 4" tall, flower buds visible	Plants 6", flower stalks 12", full bloom
Bouteloua barbata	Plants 1" tall, flowers beginning to form	Plants 2" tall, seed ripe, plants turning yellow
Cercidium microphylum		
Condalia spathulata	Green leaves present	Green leaves present, somewhat larger
Cryptantha maritima	Plants 1" tall	Plants 3" tall, flowers in full bloom
Encelia farinosa	Leaves so dry almost appear dead	Leaves whitish-green, full bloom
Erodium circutarium	Plants $\frac{1}{2}$ to 1" in diameter	Plants 2" in diameter, flowers in full bloom
Festuca octoflora	Plants 1" tall, flowers beginning to form	Plants 2" tall, seed ripe, plants turning yellow
Franseria deltoidea	Leaves so dry almost appear dead	Leaves green, full bloom
Franseria dumosa	Leaves so dry almost appear dead	Leaves green, full bloom
Gutierrezia california	Flower buds visible	First bloom
Haplopappus tenuisectus	Plants evergreen	Plants evergreen
Hymenoclea salsola	Leaves $\frac{1}{2}$ to 1" long	Full bloom
Kramera spp.	No new leaves, plant dry from drought	Many young leaf bundles, $\frac{1}{4}$" long
Larrea tridentata	Plants evergreen, some are very gray (ashen) because of drought	Plants more green, full bloom
Olneya tesota	Leaves curling from drought, gray-green	Leaves healthy, darker gray-green
Plantago purshii	Plants 1" tall, flower buds visible	Plants 2" tall, flowers dead, seed green
Prosopis juliflora	No leaves present, trees bare	Leaflets 1-3" long, full bloom
Psilostrophe cooperi	Plant green, flower buds visible	Full bloom

1975 ARIZONA PHENOLOGY

Plant Name	Phenological Stage	
	4/5-11	5/10-11
Salazaria Mexicana	Some leaves present, many bare branches	Leaves green, full bloom
Zinnia pumila	Leaves green, flower buds visible	Full bloom

1975 MONTANA PHENOLOGY

Plant Name	Phenological Stage 5/18	6/5	6/23	7/11	7/29
Achillea lanulosa	Plants 3" tall	Plants 6" tall	First bloom	Full bloom	Flowers still present
Agropyron cristatum	6" leaf growth	Flower stalks 8" long	Seed heads fully out	Flowers in peak of bloom	Seed still green
Agropyron smithii	4" leaf growth	Flower stalks 4" long	Seed heads fully out	Flowers in peak of bloom	Seed still green
Agropyron spicatum	4" leaf growth	Flower stalks 6" long	Seed heads fully out	Flowers in peak of bloom	Seed still green
Andropogon scoparius	Plant dry	Plant dry	1" leaf growth	3" leaf growth	Flower stalks appear
Aristida longiseta	3" leaf growth	Flower stalks 5" long	Seed heads fully out	Flowers in peak of bloom	Awns turning reddish-brown
Artemisia campestris	Plants 2" tall	Plants 4" tall	Plants 6" tall	Flowers in bud	First bloom
Artemisia cana	Plant ever-green	Leaf growth starts	Leaves still juvenile	Flower buds visible	Leaves mature
Artemisia frigida	Plant ever-green	Leaf growth starts	Leaves still juvenile	Flower buds visible	Leaves mature
Artemisia ludo-viciana	Plants 2" tall	Plants 4" tall	Plants 6" tall	Flower stalks appear	First bloom
Artemisia trid-entata	Plant ever-green	Leaf growth starts	Leaves still juvenile	Flower buds visible	Leaves mature
Bouteloua gracilis	1" leaf growth	2" leaf growth	3" leaf growth	Seed heads fully out	Flowers in peak of bloom

1975 MONTANA PHENOLOGY
(Cont.)

	Phenological Stage				
Plant Name	5/18	6/5	6/23	7/11	7/29
Bromus tectorum	2" plant growth	6" plant growth	Seed heads fully out	Flowering has stopped	Seed heads red or dry
Carex filifolia	2" leaf growth	Flower stalks 4" long	Seed heads fully out	Flowering has stopped	Seed ripe
Chrysopsis villosa	Plants 4" tall	Plants 8" tall	Flowers in bud	First bloom	Full bloom
Gutierrezia sarothrae	Plant ever-green	New leaves just showing	Plant bright green new growth	Plant bright green new growth	Flower buds visible
Juniperus hor-izontalis	Plant ever-green	Plant ever-green	Plant ever-green	Plant ever-green	Plant ever-green
Koeleria cristata	2" leaf growth	Flower stalks 4" long	Seed heads fully out	Flowers in peak of bloom	Seed ripe
Linum lewisii	Plants 4" tall	Plants 8" flowers in bud	First bloom	Full bloom	Seed ripe
Phlox hoodii	Plant ever-green	Flower buds visible	First bloom	Full bloom	Seed ripe
Pinus ponderosa	Plant ever-green	Plant ever-green	New shoot growth 1"	New shoot growth 3"	New shoot growth 5"
Poa secunda	2" leaf growth	Flower stalks 5" long	Seed heads fully out	Flowering has stopped	Seed still green
Psoralea esculenta	Plants 2" tall	Plants 4" tall	Flowers in bud	First bloom	Full bloom

1975 MONTANA PHENOLOGY
(Cont.)

Plant Name	Phenological Stage 5/18	6/5	6/23	7/11	7/29
Rhus trilobata	Plant bare, no leaf growth	Leaf growth just beginning	Leaves not yet full size	Flower buds visible	First bloom
Rosa woodsii	Plant bare, no leaf growth	Leaf growth just beginning	Flower buds visible	First bloom	Full bloom
Sarcobatus vermiculatus	Plant ever-green	Plant ever-green	Leaf growth just beginning	Leaves juvenile	Leaves nearly full grown
Spaeralcea coccinea	Plants 3" tall	Plants 7" tall	Plants 12" tall	Flowers in bud	First bloom
Stipa comata	4" leaf growth	Flower stalks 6" long	Seed heads fully out	Flowers in peak of bloom	Awns brown
Stipa viridula	4" leaf growth	Flower stalks 6" long	Seed heads fully out	Flowers in peak of bloom	Awns brown
Symphoricarpos occidentalis	Plant bare, no leaf growth	Leaf growth just beginning	All leaves not yet full size	Flower buds visible	First bloom
Taraxacum officinale	Plant green	Flowers in bud	First bloom	Full bloom	Seed ripe
Vicia americana	Plants 4" tall	Plants 8" tall	Flowers in bud	First bloom	Full bloom
Yucca glauca	Plant ever-green	Plant evergreen	Flower bud visible	First bloom	Full bloom

1975 PERCENT GREEN/TOTAL VEGETATION OF SPECIES FOUND IN ARIZONA TEST SITES

PLANT	Date: 1	2
Acgr, Prju	.00	.54
Boba	.70	.00
Cemi	.43	.68
Crma	.98	.00
Enfa	.42	.48
Erci, Plpu	.20	.00
Feoc	.97	.00
Frde	.37	.43
Frdu	.35	.88
Latr	.62	.80
Olte	.18	.45

1975 PERCENT GREEN/TOTAL VEGETATION OF SPECIES FOUND IN MONTANA TEST SITES

PLANT	Date 3	Date 4	Date 5	Date 6
Agcr	.09	1.00	.95	.00
Agsm	.70	1.01	.98	.75
Agsp	.30	.75	1.00	.97
Anoc	.00	.01	.09	.56
Arca	.42	.60	.69	.47
Ardr	.27	.65	.95	.85
Arfr	.35	.55	.64	.42
Arlo	.35	.88	1.00	.70
Arlu	.04	.82	.62	.47
Artr	.68	.75	.25	.83
ASTRA	.25	.75	1.00	.88
Atco	.98	1.00	1.00	.95
*Bocu	.00	.17	.55	.98
Bogr	.00	.17	.55	.98
Brte	.10	.43	.95	.35
Cafi	.30	.67	.98	.50
Calo	.50	.40	.70	.80
Chvi	.04	.45	.85	.93
Glle	.15	.85	1.00	.83
Kocr	.24	.68	.97	.90
Laof	.22	.95	1.00	.83
Lile	.05	.36	.71	.70
Pose	.23	.70	.97	.90
Pses	.07	.36	.66	.80
Rhtr	0.00	0.00	.25	.83
Spco	.17	.65	.98	.73
Stco	.27	.67	.88	.98
Syoc	0.00	0.00	.68	.85
Trdu	.15	.85	1.00	.83
Viam	.04	.35	.77	.86

*Estimated values of Bocu from values of Bogr

APPENDIX C FIELD SPECTRA MIXTURES USED FOR THEORETICAL PLANT COMMUNITIES

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 1

Silver Sage - Grass Flat   SWNE Sec. 25, T1N, R45E

			Percent
40302	080175	Litter, bare ground	48
40303	062475	Agsm	4
40601	062475	Pose, Stco, Brte, Arlo	5
40301	062475	Bogr (dry)	2
40501	062475	Kocr	11
50503	062475	Trdu, Agsp	4
60104	062375	Glle	4
40103	062475	Arca	14
40101	062475	Rhtr	5
40102	062475	Artr	1
40107	062475	ASTRA	2

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 2

Barren Hillside   SE Sec. 18, T1N, R46E

			Percent
40201	062475	Red-white soil (moist)	23
40202	062475	Small red rock pavement	7
40203	062475	White soil	22
40204	051775	Large red sandstone	4
40205	060475	Yellow sandstone cobble	6
40206	060475	Large yellow sandstone rock	8
40208	062475	Orange cobble	7
40209	062475	Red-purple rock	4
40211	062475	Red-orange rock	4
50503	062475	Trdu, Agsp	2
40606	062475	Agsp	2
40210	062475	Atco	11

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 3

Upland Grass   NE Sec. 19, T1N, R46E

			Percent
40302	080175	Litter, bare ground	35
60203	062375	Light soil	10
60204	062375	Dark soil	9
50501	062475	Agsm, Stco	7

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 3 (Cont.)

40601	062475	Pose, Stco, Brte, Arlo	1
40301	062475	Bogr (dry)	6
40101	062475	Rhtr	3
40103	062475	Arca	1
40501	062475	Kocr	6
40502	062475	Cafi	10
50503	062475	Trdu, Agsp	5.5
40504	062475	Calo	1
60104	062375	Glle	5.5

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 4

Pine - Bunchgrass NW Sec. 24, T1N, R45E

			Percent
60203	062375	Light soil	20
60204	062375	Dark soil	20
40206	060475	Large yellow sandstone rock	3
40101	062475	Rhtr	2
40103	062475	Arca	2
50503	062475	Trdu, Agsp	2
40105	062475	Syoc	1
40501	062475	Kocr	2
40502	062475	Cafi	3
40401	062475	Pipo	27
50501	062475	Agsm, Stco	2
40601	062475	Pose, Stco, Brte, Arlo	1
40604	080275	Bocu	1
40605	062475	Ansc	2
40606	062475	Agsp	8
50301	062475	Juho	3
50408	062475	Arfr	1

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 5

Ridgetop SENW Sec. 25, T1N, R45E

			Percent
60203	062375	Light soil	32
60204	062375	Dark soil	30
40503	062475	Red lichen covered rock	6
40501	062475	Kocr	1

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 5 (Cont.)

40502	062475	Cafi	15
50503	062475	Trdu, Agsp	2
40301	062475	Bogr (dry)	7
50408	062475	Arfr	4
60104	062375	Glle	2
40504	062475	Calo	1

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 6

Bluestem Hillside SENW Sec. 25, T1N, R45E

			Percent
60203	062375	Light soil	28
60204	062375	Dark soil	16
40202	062475	Small red rock pavement	4
40205	060475	Yellow sandstone cobble	4
40206	060475	Large yellow sandstone rock	1
40601	062475	Pose, Stco, Brte, Arlo	3
40605	062475	Ansc	25
40606	062475	Agsp	1
40301	062475	Bogr (dry)	5
40101	062475	Rhtr	1
50503	062475	Trdu, Agsp	2
40502	062475	Cafi	3
40504	062475	Calo	1
60103	062375	Yugl	4
60104	062375	Glle	2

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 7

Grass - Dandelion Bottom SESW Sec. 24, T1N R45E

			Percent
60203	062375	Light soil	30
60204	062375	Dark soil	17
40301	062475	Bogr (dry)	16
40303	062475	Agsm	6
40501	062475	Kocr	3
40701	062475	Taof	28

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 8

Coal Mine Fire Rehab. Area NESE Sec. 24, T1N, R45E

		Percent
40801	060475 Light soil (dry)	13
40803	060475 Light reddish soil (dry)	33
40804	060475 Milk-white soil	21
40805	060475 Dark gray soil	17
40103	062475 Arca	4
50501	062475 Agsm, Stco	1
50104	062475 Kocr	1
60401	062375 Agcr (seeded pasture)	10

LISCOM CREEK - MONTANA PLANT COMMUNITY No. 9

Alfalfa - Grass Pasture SESE Sec. 14, T1N, R45E

		Percent
60203	062375 Light soil	15
60204	062375 Dark soil	15
40901	062475 Alfalfa	35
40902	062475 Hayfield (rye)	35

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 1

Ridgetop NW Sec. 6, T1N, R50E

		Percent
50101	051875 Light rocky soil	12
50102	051875 Dark gravelly soil	6.3
50105	062475 Dark soil	6.4
50106	062475 Reddish soil	6
50107	062475 Tan outcrop	2
50108	080175 Dark bare soil	6.3
50405	060475 Light soil	18
50103	062475 Agsp	1
50104	062475 Kocr	8
50302	062475 Artr	5
50303	062475 Arca	3
50501	062475 Agsm, Stco	6

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 1
(Cont.)

50503	062475	Trdu, Agsp	5
60104	062375	Glle	5
50408	062475	Arfr	4
50403	062475	Bogr	4
50110	062475	Cafi	2

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 2

Barren Hillside SWSW Sec. 1, T1N, R49E

			Percent
50201	060475	Cream-colored soil	32
50202	051875	Light gray-white soil	31
40205	060475	Yellow sandstone cobble	10
50504	080175	Large yellow sandstone rock	11
50503	062475	Trdu, Agsp	1
40210	062475	Atco	2
40604	080275	Bocu	1
50103	062475	Agsp	4
50302	062475	Artr	3
50304	062475	Rhtr	2
50305	062475	Yugl	1
50502	062475	Ansc	1
40602	080275	Stco	1

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 3

Grass - Yucca Rolling Hills SENE Sec. 1, T1N, R49E

			Percent
50105	062475	Dark soil	30
50405	060475	Light soil	31
50503	062475	Trdu, Agsp	1
50501	062475	Agsm, Stco	10
50104	062475	Kocr	5
50304	062475	Rhtr	1
50305	062475	Yugl	6
50403	062475	Bogr	5
50110	062475	Cafi	11

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 4

Grass Bottom — SESW Sec. 1, T1N, R49E

			Percent
50105	062475	Dark soil	20
50404	060475	Dark rocks, light soil	13
50405	060475	Light soil	15
50503	062475	Trdu, Agsp	2
40701	062475	Taof	3
40601	062475	Pose, Stco, Brte, Arlo	1
60104	062375	Glle	3
60201	062375	Agsm, Brte	9.6
50104	062475	Kocr	9
50110	062475	Cafi	2
50403	062475	Bogr	19.4
40303	062475	Agsm	3

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 5

Bluestem Hillside — NW Sec. 6, T1N, R50E

			Percent
50105	062475	Dark soil	13
50404	060475	Dark rocks, light soil	21
50405	060475	Light soil	13
50504	080175	Large yellow sandstone rock	13
50503	062475	Trdu, Agsp	2
60104	062375	Glle	2.5
50104	062475	Kocr	1
50301	062475	Juho	8
50305	062475	Yugl	1
50403	062475	Bogr	2
50110	062475	Cafi	1
50408	062475	Arfr	3
50501	062475	Agsm, Stco	2
50502	062475	Ansc	16
50503	062475	Trdu, Agsp	.5
40303	062475	Agsm	1

ALLEN RANCH - MONTANA PLANT COMMUNITY No. 6

Shortgrass - Drainage Bottom   SWNW Sec. 6. T1N, R50E

			Percent
50105	062475	Dark soil	16
50405	060475	Light soil	15
50503	062475	Trdu, Agsp	6
40701	062475	Taof	10
50104	062475	Kocr	10
40303	062475	Agsm	1
50601	062475	Pose, Bogr (short green)	42

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 1

Ridgetop (NW)   SWSE Sec. 5, T2N, R53E

			Percent
60101	062375	Bare soil	62.9
60105	062375	Buff rock	2
40303	062475	Agsm	4
40504	062475	Calo	.01
50408	062475	Arfr	6.19
50403	062475	Bogr	3
60102	062375	Kocr, Cafi, soil	4.1
60103	062375	Yugl	2
60104	062375	Glle	4
40606	062475	Agsp	.8
40101	062475	Rhtr	7
60601	062375	Artr	4

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 2

Rolling Hill Grassland   NWNE Sec. 8, T2N, R53E

			Percent
60203	062375	Light soil	45
60204	062375	Dark soil	25
40701	062475	Taof	1
50403	062475	Bogr	17
50408	062475	Arfr	1

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 2 (Cont.)

60104 062375 Glle	1
60201 062375 Agsm, Brte	10

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 3

Shortgrass - Drainage Bottom SENE Sec. 15, T2N, R53E

	Percent
60203 062375 Light soil	23
60204 062375 Dark soil	12
60201 062375 Agsm, Brte	3.2
60202 062375 Arca	1.2
50104 062475 Kocr	9.7
50110 062475 Cafi	16.2
60103 062375 Yugl	28.2
60302 062375 Bogr (short), Taof	6.5

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 4

Seeded Grass Bottomland NESW Sec. 10, T2N, R53E

	Percent
60402 062375 White bottom soil	58
40701 062475 Taof	1
50503 062475 Trdu, Agsp	1.5
50104 062475 Kocr	4
60104 062375 Glle	2.5
60401 062375 Agcr (seeded pasture)	18
50403 062475 Bogr	8
60201 062375 Agsm, Brte	6
60202 062375 Arca	1

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 5

Barren Hillside NESW Sec. 15, T2N, R53E

	Percent
60504 062375 Tan cobbled pavement	3
60501 060275 Orange cobble rock	3

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 5 (Cont.)

60502	060275	Yellow-orange cobble	4
60503	060275	Bentonite	27
60505	062375	White soil	15
60506	062375	Reddish rock	3
60507	073175	Red rock pavement	3
60508	073175	Large yellow sandstone rock	4
60509	073175	Yellow rock pavement	4
40101	062475	Rhtr	5
40303	062475	Agsm	5
60104	062375	Glle	1
60601	062375	Artr	19
60602	062375	Agsp	4

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 6

Arca-Artr-Grass - Rolling Hills SESE Sec. 8, T2N, R53E

			Percent
60203	062375	Light soil	31
60204	062375	Dark soil	17
40701	062475	Taof	3
50503	062475	Trdu, Agsp	3.5
50104	062475	Kocr	2
60104	062375	Glle	3.5
40602	080275	Stco	2
40601	062475	Pose, Stco, Brte, Arlo	1
50302	062475	Artr	9
50403	062475	Bogr	13
40502	062475	Cafi	3
50408	062475	Arfr	3
60202	062375	Arca	8
60602	062375	Agsp	1

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 7

Silver Sage - Grass Bottom SWNE Sec. 16, T2N, R53E

			Percent
60204	062375	Dark soil	23
40701	062475	Taof	1
50503	062475	Trdu, Agsp	3.5
40105	062475	Syoc	5

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 7
(Cont.)

50104	062475	Kocr	3
50302	062475	Artr	3
50403	062475	Bogr	8
40303	062475	Agsm	9
60104	062375	Glle	4.5
60202	062375	Arca	40

SCOTT RANCH - MONTANA PLANT COMMUNITY No. 8

Ridgetop (SE)

NESW Sec. 15, T2N, R53E

			Percent
60203	062375	Light soil	26
60204	062375	Dark soil	28
60502	060275	Yellow-orange cobble	3.5
60506	062375	Reddish rock	2
60507	073175	Red rock pavement	7
60508	073175	Large yellow sandstone rock	2
60509	073175	Yellow rock pavement	3.5
50503	062475	Trdu, Agsp	3
50302	062475	Artr	12
50408	062475	Arfr	3
60104	062375	Glle	3
60602	062375	Agsp	7

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